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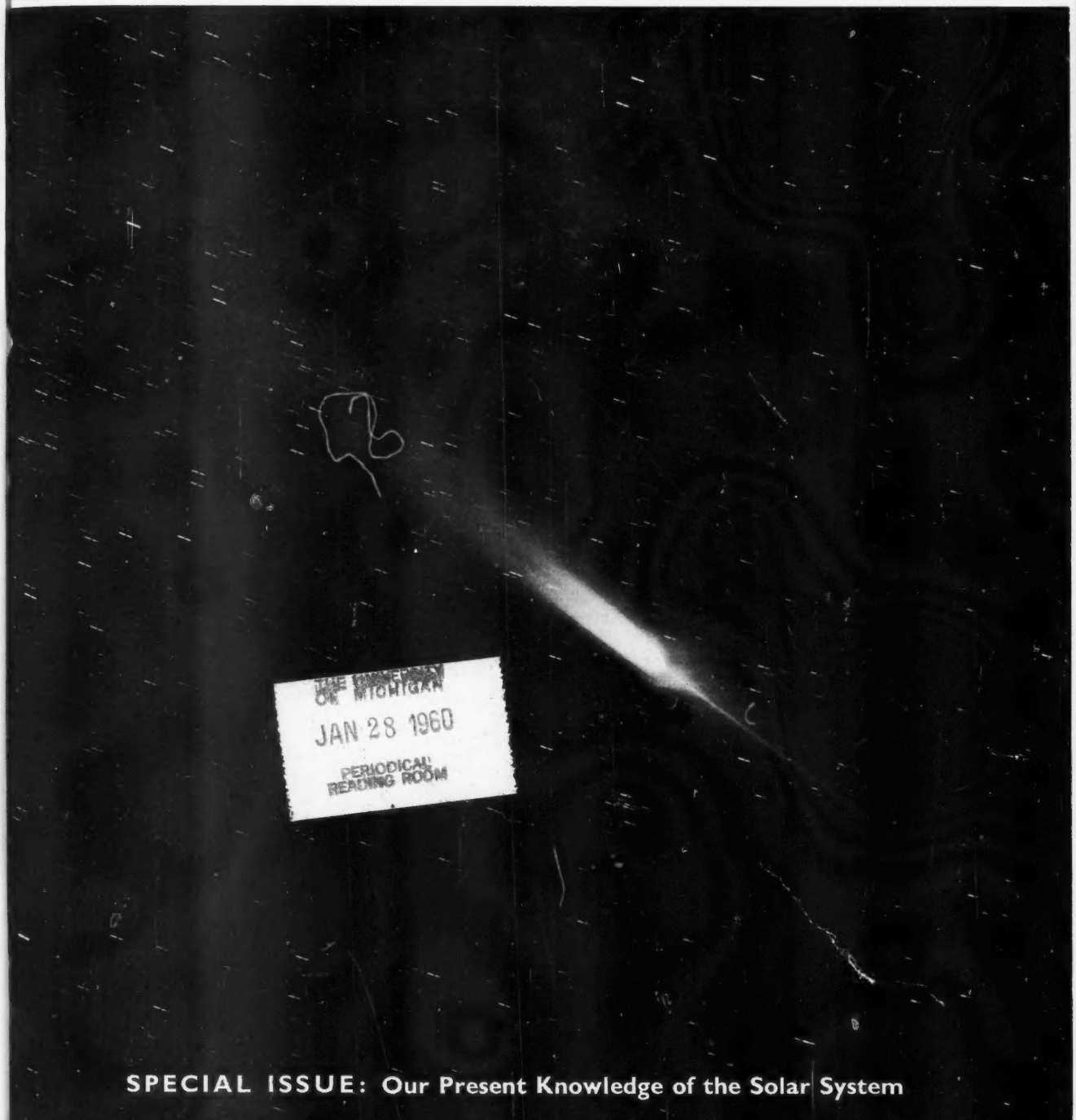

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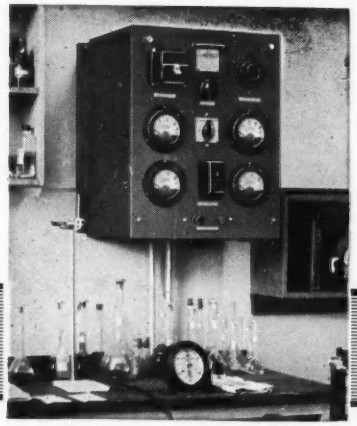

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OUR COVER PICTURE

Comet Arend-Roland, photographed on April 24, 1957, by R. L. Waterfield at his private observatory at Ascot.

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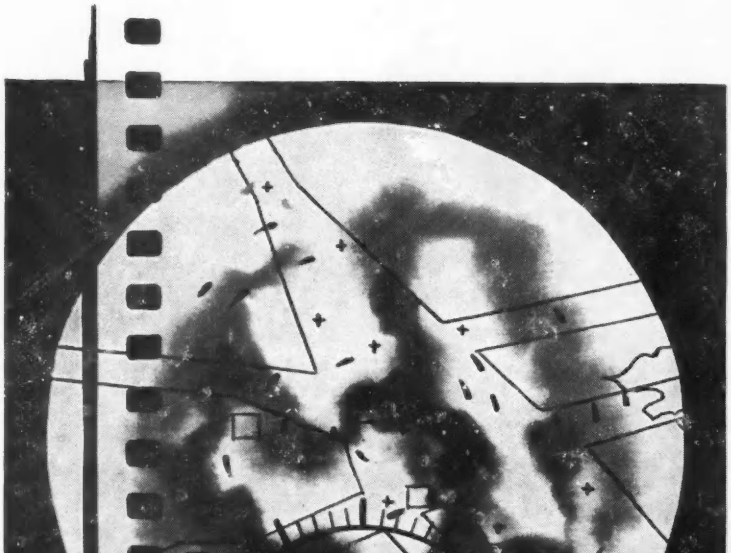

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A SURVEY OF OUR PRESENT KNOWLEDGE OF THE SOLAR SYSTEM

THE DECADE OF SPACE RESEARCH BEGINS

As we now enter the second decade of the second half of the 20th century, it seems likely that one of mankind's dreams—voyaging into space—is about to become solid reality. No longer is space-travel the exclusive realm of the writer of science fiction—it is now also the province of the research scientist. Indeed, the exploration of space by man-made vehicles carrying automatic instruments has already advanced to such a stage that one cannot now be certain that each new attempt will even reach the headlines of the newspapers. It is not, therefore, untoward to expect that, before long, papers dealing with the scientific aspects of man's expeditions to the Moon, to Mars, and to Venus, will be appearing in the *Proceedings of the Royal Society* and other journals of a like kind.

There have, of course, been those who could see only the difficulties which lay ahead, and who, limited by the confines of their own personal scientific outlook, imitated the mistakes of equally noble predecessors and doubted the practicability of any kind of space project. But one of the most startling aspects of what at least one national newspaper has called "the space age", is the prodigious speed with which it has come upon us and blasted away the cobwebs of disbelief. The Americans and, most notably, the Russians have been in the vanguard of progress in rocket technology. Already Russian space-vehicles have reached the Moon and have also been put into orbit round it, and it does not seem to be asking too much to expect that before this new decade is over, man—ever voracious for knowledge and adventure—will be treading the soil of at least one of his nearer planetary neighbours.

However, exciting and enthralling though space exploration is, we must try to see it in its true perspective. It is, in essence, an extension of man's methods of observing and investigating the universe in which he finds himself. After all, mankind has always been insatiably curious about the Sun, the Moon, and the planets. Study of these bodies and their apparent paths in the sky was almost the *raison d'être* of astronomy from the dawn of human history until the advent of the telescope, a little over three hundred years ago. Unfortunately, there is sometimes a tendency to disparage the work of the earliest astronomers—to look down our noses at the Sumerians and those who followed them—to feel ourselves vastly superior to the Greeks, who made such valiant efforts to formulate a cosmology and reduce to geometrical simplicity the complex paths of those planets visible to the naked eye. But if only we can appreciate, even a little, the limitations imposed on these early observers and philosophers due to the fact that they had no means of exploring space except with their unaided eyes or the comparatively crude instruments which they were able to construct, we shall perhaps appreciate that, in the long run, our knowledge of the universe is always proportional to the means developed for investigating it.

Great strides in understanding the motions of the planets and in ability to compute their future paths were made in the 16th century, and especially the 17th century. Copernicus made his proposals for a Sun-centred or heliocentric system, and was followed by Kepler, who, working on the accurate and painstaking observations of Tycho Brahe, put forward the revolutionary idea that the planets moved not in circles but in ellipses and formulated the "laws" of their motion. Isaac Newton then came into the picture and correlated these laws of celestial motion with the motion of terrestrial bodies, and thus gave the scientific world a hypothesis which has been fruitful to a degree it is hard to overstress. Coupled with these great advances in dynamical astronomy there came, at the beginning of the 17th century, the invention of the telescope. With this instrument there was at last available to astronomers the first means for examining the physical nature of the Sun, the Moon, and the planets. A new means of space exploration had arrived.

In the 19th century further observational advances were made. The analysis of light by the spectroscope proved to be yet another means of exploring the heavens and enabled investigation of such questions as the nature of planetary atmospheres. The advent of photography also had great implications, primarily in stellar and positional astronomy, although it proved an important tool for the study of the Sun and the Moon. However, there are technical reasons why planetary and lunar studies are still especially the province of the amateur astronomer, who continues to make most valuable contributions. The 20th century has seen the development of radio-astronomy and the opening of yet another new phase in conquering space. Already this new technique has produced outstanding results and, clearly, is a powerful weapon in the hands of the modern astronomer.

Now we may soon be able to voyage out into space itself. In the future we can look forward to investigations of the universe untrammelled by the limitations imposed by our terrestrial atmosphere, and to physical exploration of our closer celestial neighbours. International co-operation is needed for this work, and already proposals for a world-wide conference under the auspices of the United Nations has been made. Let us fervently hope that in this the scientist will not allow himself to be chained within the limitations of the politicians' understanding—he has already proved his organising ability in the IGY and must be left to his own methods if scientific exploration is to be both possible and fruitful.

With this new adventure in mind, it is appropriate if we stand still for a moment and take stock of the knowledge of the Solar System which the "Earth-bound" astronomer has made. It is a wonderful and immensely interesting story as well as a tribute to the mind and ingenuity of man, as is shown in the six articles which follow.

THE ORIGIN OF THE SOLAR SYSTEM

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Choice between rival hypotheses about the origin of the Solar System is hindered by the fact that there is only one available for study, for it is not possible to distinguish significant features which demand explanation from those which are accidental and do not.

Questions about the origin of things have always had a peculiar fascination for the human mind. Yet such questions pose many difficulties when applied in a scientific context. For the answer that one gives to any question of "origins" depends upon the way in which the question is asked, and the framing of the question is determined by very broad attitudes about the nature and evolution of the universe as a whole.

For example, Edmund Gosse relates (in his book, "Father and Son") how his father, Henry Gosse, an eminent 19th-century zoologist and a Plymouth Brother, was much exercised as to how to reconcile the evidence for the Earth's antiquity given by geological studies with the chronology of the Bible that led to the belief that the Earth was created in 4004 B.C. Eventually, he proposed the view that the Earth was created in 4004 B.C., but in such a form (with, for example, all the fossils created *in situ*) as to be consistent with its being of "geological" age. Not only was this a reasonable answer in the framework of Henry Gosse's accepted cosmology, it was the *only* answer. Yet it hardly commends itself to the modern scientific viewpoint.

Similar problems arise when discussing the origin of the universe. Broadly speaking, modern cosmologies can be divided into two categories. The first, the "explosive" or "evolutionary" theories, suppose the universe to have "begun" as a singular state (either a single gigantic atomic nucleus, or a uniform distribution of fundamental particles). The word "begun" here means simply that, as the initial state is a singular state, scientific methods cannot follow backwards the train of cause and effect prior to this "singular state". The other theories, "steady state" theories, suppose that although the individual entities in the universe may evolve and change, the universe as a whole remains statistically the same. On the steady state theories, the general properties of the universe should be related to each other in a way amenable, in principle, to scientific analysis —the universe is as it is because it has always been so, and always will be so. With evolutionary theories, the relationships are time-dependent, so that the present state of the universe is ultimately related to the initial singular state—the universe is as it is because it was as it was. Clearly, neither answer would have satisfied Henry Gosse!

Questions about the origin of the universe suffer from the fact that there is, by definition, only *one* universe. It is therefore neither possible nor meaningful to distinguish between the accidental and the significant features of the universe. A similar problem arises with the question of the origin of the Solar System. Although we might conceive of there being a multiplicity of such systems—every star might have planets—we have only our own Solar System accessible to detailed observation. (It should be noted, however, that very precise observations of some score of nearby double stars suggests that they may have invisible companions of planetary, rather than stellar, mass.) Thus any theory of the origin of the Solar System, however improbable the postulated state of the universe which is supposed to give rise to the system, *might* be the "right" one, since given sufficient time (and on the steady state theories we have an infinite time) any particular combination of circumstances might arise.

Logically, therefore, it might be taken as a possibility that the Solar System arose by the successive capture by the Sun of the planets, satellites, comets, minor planets, and meteors that make up our Solar System as it is today. But this hypothesis represents a *very unlikely* one, because of the regularities (the *organisation*) that the Solar System exhibits, and the hypothesis is generally considered to be aesthetically unsatisfactory.

The regularities in the Solar System can be broadly summarised:

(i) the direction of revolution of all the planets, and the majority of minor planets and meteors, about the Sun is the same—there is a "one-way sign" in the Solar System;

(ii) the sense of rotation of all of the planets (except Uranus) and the sense of revolution of all the satellites (except those of Uranus and the outer satellites of the major planets) is the same as the sense of planetary revolution;

(iii) the planes of the orbits of the planets are nearly the same, inclinations not exceeding a few degrees (this is less true of the minor planets and hardly true at all of the comets);

(iv) the distances of the planets follow some general sort of pattern, of which Bode's Law is one (but by no means the most accurate) of the formulae used to represent the planetary distances;

(v) the rotation of the Sun on its axis follows the general sense of rotation of the system.

These regularities strongly suggest that the Solar System as a whole was formed by a single organic process which involved the Sun. Some support for this view comes from the measurement of the ages of the Earth and the Sun. From the relative proportions of uranium and lead in the crust of the Earth, and knowing the rate at which a collection of uranium atoms spontaneously disintegrates in a series of radioactive processes leading to the formation of lead, the age of the crust of the Earth is found to be about 4 thousand million years. This is comparable with the age of the Sun, deduced from theories of stellar structure and evolution, of between 5 and 8 thousand million years. It is also of the same order as the characteristic time-scale found from the expansion of the universe, although modern measurements of the distances of distant star-systems give the "age of the universe" (on the explosive theories) as several times greater than this figure. We should note, therefore, that while on steady state cosmologies, we must

find a mechanism for forming "solar systems" in the universe as it is today, on "evolutionary" cosmologies, the Solar System was formed when the general characteristics of the universe were very different from those we observe today, and such differences might have a bearing on the nature or probability of any theory of the origin of the Solar System.

GENERAL THEORIES

The first scheme which was proposed to account for the general regularities of the Solar System was that of Laplace, published at the end of the 18th century (although bearing some relationship to the earlier ideas of Kant). Laplace conceived of the whole Solar System, including the Sun, as originating in a condensation of a large mass of diffuse gas. If this mass had a very slight rotation, however small, the process of contraction would cause the angular velocity to increase. This is a consequence of the "law of conservation of angular momentum" for any dynamical system for which the forces between any two component points are directed (as is the force of gravitation) in the line joining the points. For circular motion, angular momentum is measured by the sum of the products of the mass of each particle (m), its orbital speed (v), and its orbital radius (r) (that is, each particle carries with it an angular momentum $m.v.r$). Thus, as the proto-Solar System contracted, and r decreased, v must have increased.

There would come a time, however, when the gravitational attraction of the central parts of the proto-Solar System was unable to retain the rapidly moving outer parts in circular orbits—the centrifugal forces of rotation become important compared with the gravitational forces. The contracting mass would assume a lens shape, and eventually material would be ejected from the rim of the lens like mud thrown from the rim of a rotating bicycle-wheel. This material was supposed by Laplace to condense into planets, the discrete planets being formed because the material was ejected in a series of rings. The remaining core condensed to form the Sun.

This "nebular hypothesis" cannot be called a "theory" because it was only described qualitatively and not worked out quantitatively. When it was examined in numerical detail, it was found to be wanting. In the first place, the ejected material could not have condensed into solid bodies; it would have rapidly dispersed (that is, evaporated) into space. Secondly, the total angular momentum of the system was not enough to form planets as far out as Neptune and Pluto, for, if all the planets and the Sun were supposed to be merged into a single body the size of Pluto's orbit, its angular momentum would hardly be sufficient to give it slight flattening, let alone enough to allow of the ejection of material.

This second difficulty could be overcome if it were supposed that the actual material of the planets is but a very small fraction (less than 1%) of the total amount of material ejected, the remaining material having dissipated into space. This is not, of course, unlikely. The different chemical compositions of the planets like the Earth and planets like Jupiter and Saturn (which contain a higher proportion of lighter elements) can be explained by the loss of the lighter gases from the less massive planets nearer the Sun. Similarly, the small proportion of hydrogen in even the major planets, compared with the Sun, could be understood if most of the ejected material had been in the form of hydrogen, which was lost to the system.

But the nebular hypothesis failed fundamentally on the question of the *distribution* of angular momentum between the Sun and the planets. It can be shown that in any system contracting under its self-gravitation, each unit mass of material would carry exactly the same amount of angular momentum as any other unit mass. In the Solar System the orbital motion of the planets account for 98% of the total angular momentum of the system, while the solar rotation accounts for only 2%—yet the total mass of all the planets added together amounts to only about 0·1% of the mass of the Sun.

THE TIDAL THEORY

On the nebular hypothesis, the Solar System was formed as an integral part of the process of formation of the Sun, so that on this hypothesis most if not all stars could be expected to have their attendant planets. The nebular hypothesis is therefore an example of a "general" theory. In contrast, we might have a "particular" theory which postulated a special set of initial conditions for the formation of the system, conditions that might not apply for most stars at any stage of their history. Such a theory is the "tidal theory", which was current during the period between the first and second world wars, associated with the names of Jeans and Jeffreys.

The tidal theory connected the planetary system with a close approach of another star to the Sun, the intruder moving about the Sun in a hyperbolic orbit. Such an intruder would raise gigantic tides in the surface of the Sun, and a bridge of material would form between the Sun and the other star. From this material, the planets were supposed to have condensed. Such a close approach of two stars is very unlikely; in conditions as we find them today, only one star in many millions would suffer such close encounters. But there are many thousands of millions of stars in our own galaxy alone. If the universe had been much denser in the past, as on "evolutionary" cosmologies, encounters might have been less unlikely.

The improbability of the basic conditions is not, as we have seen, any valid argument against the theory. This theory hoped to overcome the angular momentum problem by providing angular momentum for the planetary orbits from the motion of the intruder, but a closer analysis shows that this attempt failed. The intruder would not only have raised large tides, but would also have speeded up the solar rotation. A more promising variant of the tidal theory was developed by Lyttleton just before the second world war. He supposed that the Sun had been originally a member of a binary star system. The intruder raised tides in the Sun's companion, and disrupted the binary star. The angular momentum of the planetary orbits was then derived from the original orbital motion of the Sun's companion about the Sun. While the binary star theory may overcome the difficulty of producing planets at the distance of Jupiter while having a slowly rotating Sun, it does not explain how any planets found their way closer to the Sun than Jupiter. Furthermore, it only pushes the problem of origin back to the question of origin of a binary star system with a non-uniform distribution of angular momentum. Some authors have, in fact, seen the problem of the origin of the Solar System as a special case of the problem of the origin

of multiple star systems. Both versions of the tidal theory have encountered difficulties in getting the planets to condense out of the tidal filaments.

Recent theoretical work on the outflow of heat from a planet such as the Earth, with some of the internal heat being provided by radioactive minerals, has led to the view that the Earth (and, presumably, the other planets) has not condensed from hot material, but been built up by "cold accretion". Here, the original condensations are supposed to be small particles, or "planetesimals", which aggregate together by their mutual gravitational attraction, aided perhaps by the chemical property of "stickiness". Such particles are observed in interstellar dust-clouds, where they form in the very diffuse interstellar medium. This might lead to the suggestion that in some way the planetary system was formed out of condensation of interstellar matter which already contained these "planetesimals".

SCHMIDT'S THEORY

The Russian astronomer O. Schmidt has developed a highly sophisticated theory of the origin of the planetary system in the encounter by the Sun of an interstellar cloud. The process of cold accretion is of itself sufficient to produce planets with circular orbits lying close to a single plane, since the resultant orbit of a planet is a mean of the orbits of the planetesimals out of which it was formed. The particles in the dust cloud, which also had a gaseous component, were supposed to contain volatile constituents, the successive evaporation of the various constituents at different distances from the Sun giving rise to the gradual change in the chemical composition of the planets with distance from the Sun. Among the other features of the Solar System that Schmidt believed to arise naturally from his theory was a law of planetary distances that bore a reasonable resemblance to Bode's Law. In many ways Schmidt's theory is the most highly developed of those in the field.

In Schmidt's theory, the cloud of material that formed the planets was independent of the formation of the Sun, the planets arising from a chance encounter. The problem of the distribution of angular momentum between the Sun and the orbits of the planets does not arise here, for the angular momentum of the planetary system can be supposed to be derived from angular momentum present in the original interstellar cloud. Schmidt believed that this angular momentum was present in the form of differential galactic rotation—for in the region of the galaxy near the Sun, the individual stars and other material are moving essentially under the attraction of the massive central part of the galaxy, so that material nearer to the centre of the galaxy has a greater orbital velocity than more distant material. A condensation in the interstellar medium would thus have, from the start, some angular momentum as part of the general angular momentum of the galaxy, which it would retain by increasing its velocity of rotation as it contracted. There is, however, no reason why the solar rotation should be in the same general direction as the motion of the planets.

Inasmuch as Schmidt's theory postulates a special set of conditions for the origin of the Solar System, the process of origin not being an integral part of the formation of the Sun, his theory must be classed as a "particular" theory. But the postulated conditions are not at all stringent, as interstellar clouds are common. The main requirement would seem to be that the relative velocity of the Sun and the cloud must be rather small, not exceeding about 1 km./sec. On Schmidt's theory, a significant fraction of the stars in the galaxy might be expected to have attendant planets.

Recently, the pendulum has swung even farther towards "general" theories. But it seems clear now that no theory that attempts to describe the origin of Sun and planets in a single process can overcome the angular momentum distribution problem while it relies solely on mechanical forces, such as gravitation. Indeed, if the Sun is supposed to have condensed from interstellar matter (and how else could it have been formed?) the angular momentum of internal motion of the proto-Sun should have given the present Sun a much more rapid rotation. In other words, we require first a mechanism that can have *slowed the Sun down*. If the same mechanism can also have pushed the planets farther from the Sun than their place of formation, the angular momentum problem is solved.

ELECTROMAGNETIC FORCES

A number of authors have seen in electromagnetic forces a possible mechanism for transfer of angular momentum from the Sun to the planets. A condensation in the interstellar gas would certainly, at some stage, be highly ionised and would have a high electrical conductivity; in fact, it would constitute what is now known as a "plasma". Because of the high conductivity, any lines of magnetic force present in the material are, so to speak, frozen into it, and move with it. Now there are many reasons (among them the emission of radio waves by the galaxy) for believing that there are weak but widespread magnetic fields threading the galaxy. Any part of this galactic magnetic field trapped in a condensing proto-Sun would be intensified by the contraction which would bring the lines of force closer together. In the simple case where we picture lines of magnetic force initially radiating from the Sun, we see that the presence of the magnetic field tends to constrain the contracting cloud to rotate with a *uniform* angular velocity. On the other hand, the gravitational forces tend to constrain the cloud to rotate with a greater angular velocity nearer the centre, and a smaller angular velocity nearer the rim (that is, a uniform distribution of angular momentum per unit mass). If the electromagnetic forces are significant compared with the gravitational forces, they will modify the behaviour of the system. In fact, in attempting to reach a state of uniform angular velocity in the contracting cloud, electromagnetic forces will tend to slow down the rotation of the core (the Sun) and push the outer regions (from which the planets will form) away from the Sun. The system will depart radically from a uniform distribution of angular momentum.

Why will the material not be pushed completely away from the Sun? Probably much of it will be, but as soon as solid particles form in the gaseous condensation, they will be immune from the electromagnetic forces and will remain circling the Sun under gravity alone. We can picture the planetary material being left behind as planetesimals as the plasma material recedes from the Sun. Planets must be supposed to arise at discrete distances from the Sun because conditions suitable for the solidification of different elements occur critically as discrete distances. This leads

to the idea of a sequence of planets with different chemical compositions—which indeed is, broadly speaking, found in the Solar System.

An example of a theory invoking electromagnetic forces in this way is that of Hoyle. Hoyle accepts the steady state approach to cosmology, and must therefore find some conditions in the universe as it is today where heavy elements can be synthesised from hydrogen. (The "explosive" cosmologists picture the heavy elements as being formed at a primeval state of their universe.) The only likely locations for heavy-element synthesis are the interiors of supernovae—stars which become unstable and explode, thus dissipating their material into space. Since the planets contain heavy elements, they must have been formed from material once inside a supernova. In an early version of this theory, the Sun was supposed to have a supernova as a companion in the past, the explosion of this companion providing not only the material but also the angular momentum of the planets. But now that we have reason to believe that stars form in the interstellar medium, not singly but in groups of, say, fifty, it is only necessary to suppose (a not highly improbable supposition) that one of the solar group became a supernova in the past. The angular momentum distribution problem is solved by electromagnetic braking, as outlined above.

This outline is, of course, a great simplification. (For example, if electromagnetic forces can cause the material of the outer parts of the condensation to move away from the Sun, why did it ever condense in the first place? During the initial condensation process, the material must be unionised.) Perhaps one of the aspects that makes electromagnetic forces so attractive in this problem is that we do not yet understand enough about plasma physics to make a fully quantitative theoretical treatment of the interaction process. (As one eminent astronomer has been heard to remark, "Features of the Solar System that used to be attributed to the Deity are now attributed to Electromagnetism.") But, for obvious reasons quite unrelated to astrophysics, plasma physics is now being developed rapidly and fruitfully, and this is bound to have an impact on our theories of the origin of the planets. For whatever the final judgment on our present theories, there is no doubt that we cannot any longer ignore electromagnetic forces.

THE PERFECT THEORY?

How, then, should we view this plethora of theories of the origin of the Solar System? While to its author each theory may seem to have a rightness, an inevitability that is aesthetically satisfying, to the impartial observer there seems to be a prevalent tendency to make *ad hoc* assumptions about the initial conditions to explain particular features of the Solar System as it is today. None of the theories would emerge unscratched from a determined attack with Occam's Razor. And there remains the factor mentioned at the beginning of this article, namely, that with only one "Solar System" available for detailed inspection (at the present time) we cannot say which features of the systems are significant and demand an explanation, and which features are accidental and do not. For example, we cannot be sure that many of the regularities of the Solar System are not due to internal forces of gravitational interaction, for the many-body gravitational problem has not been solved, and the standard methods of celestial mechanics do not admit of application for a span of time exceeding a few centuries. In trying to find an explanation for Bode's Law (for example) in conditions at the formation of the Solar System we may be chasing a chimera.

In fact, what is it that we are trying to do when we formulate a theory of the origin of the Solar System? At first sight it might seem that we are trying to find a chain of effect and cause from a complex system (the Solar System) to a simpler system (an interstellar cloud, for example). Yet we use the laws of laboratory physics in our investigations, and the second law of thermodynamics tells us that systems evolve from the less random to the more random. So that, whatever our views about the relative simplicity of the Solar System and an interstellar cloud, the process of formation of the Solar System must leave the universe as a whole, not *more* highly organised but *less* highly organised.

Indeed, it may be doubted whether it is, in principle, possible to proceed by a process of induction from the present properties of the Solar System to some prior state of the universe; and the "origin" of this prior state will remain as a problem, so that what can be considered as an "explanation" of the Solar System is a matter of personal choice. (On evolutionary cosmology, all the properties of the universe, including the Solar System, stem from the initial primeval conditions.)

Theories of the origin of the Solar System are more fruitful if they work deductively from an hypothetical prior state consistent with a particular cosmology. But even here, the ideal has yet to be reached of relating all the supposedly significant features of the Solar System to the initial hypothesis completely deductively. A theory that falls short of this ideal must be considered imperfect.

The study of the origin of the Solar System has left behind it a wake of discarded theories. To the extent that a significant aspect of science is the progressive discovery of what the universe is *not* like, this may be deemed progress. But it is legitimate to doubt whether, in a science which is concerned with the relationships *between* events in space and time, questions of origin can be properly formulated at all. In the end, the judgment between one "theory" and another may rest on aesthetic preference. We may not see the problem as Henry Gosse did, nor yet sympathise with his solution—but are we not his brothers under the skin?

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THE SUN

M. A. ELLISON

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The immense complexity of the outer atmospheres of the Sun and Earth is just beginning to be unravelled. This is the outcome of research during the IGY which has opened an exciting chapter in this study.

The Sun is a typical star: its spectral type (G_0), its mass, and its luminosity all mark it out as an average representative of those stars which populate the spiral arms of our galaxy.

But the Sun is unique in this respect: it is the one star in the whole universe whose surface we can see. Its proximity enables us to study in great detail the continuous activity which occurs in its outer atmospheric layers and to relate this activity to the many types of radiation we receive on Earth

THE ATMOSPHERIC LEVELS

The photosphere is the deepest level to which our vision can penetrate. It has been observed with increasing precision since Galileo in 1610 projected the first solar image in white light through his small telescope. His discovery of the sunspots marked the downfall of the "perfect Sun" concept and led by slow steps to our present understanding of the highly irregular and turbulent behaviour of its atmosphere.

In 1908 Hale published his discovery of the sunspot magnetic fields. During the past five years high-resolution spectrographs and photoelectric devices have been brought into use which allow contour maps to be plotted showing in great detail the distribution of field strength in the sunspot regions. Severny, in the Crimea, and Evans, at Sacramento Peak, have reported sudden changes in the field strength at times of the spectacular outbursts near sunspots which we call solar flares. This appears to indicate that magnetic energy which is stored up in the field can be

FIG. 1. Terrestrial effects of solar flares.

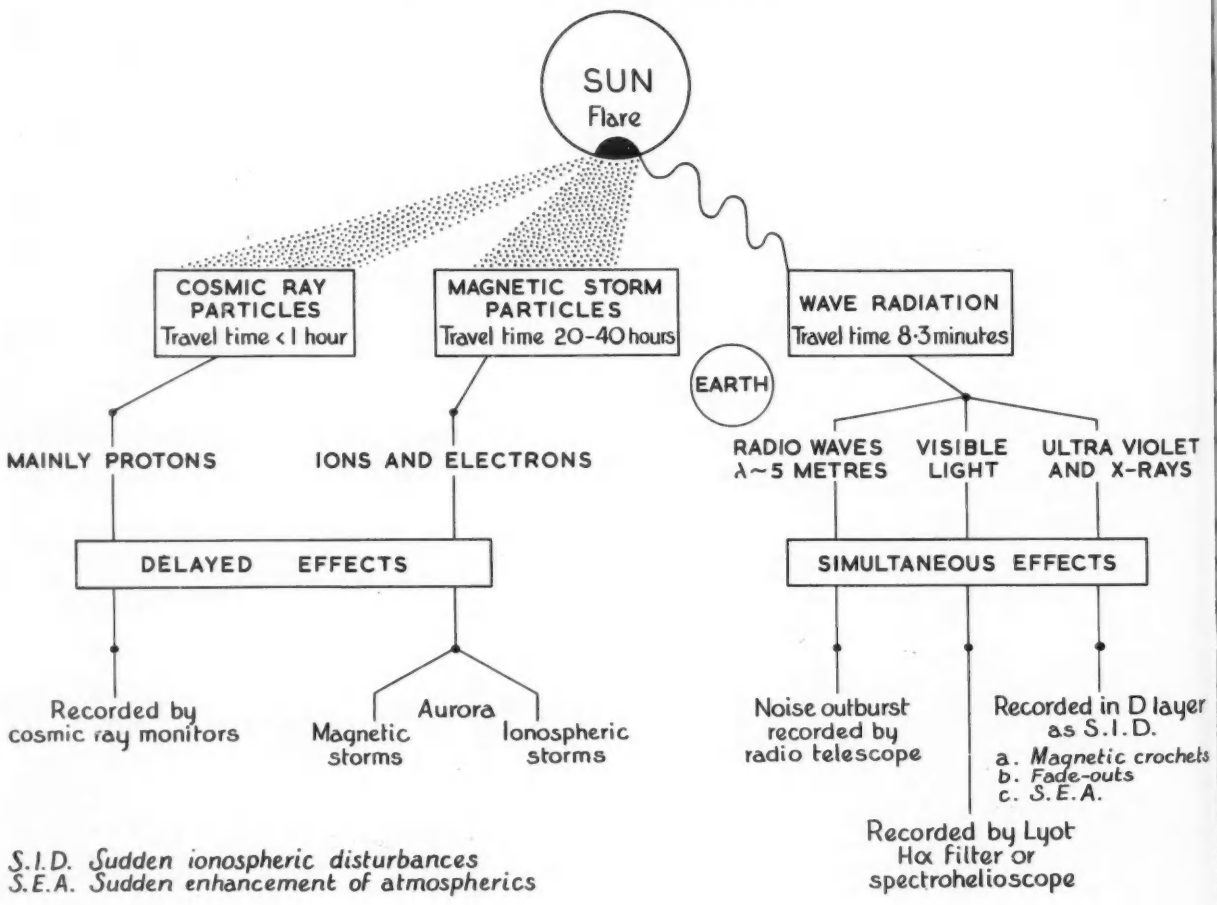


FIG. 2 (*above*). Zürich sunspot numbers (*R*), mean monthly values, 1942–59. In each daily observation *F* is the number of single spots counted, *G* is the number of groups, and *K* is a constant depending upon the method of observation.

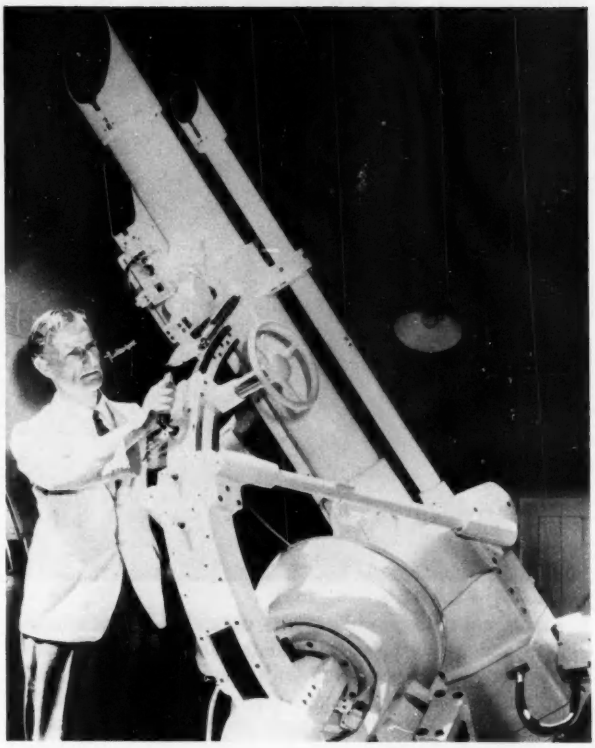


FIG. 3 (*right*). The Lyot Hα heliograph at the Royal Observatory, Cape of Good Hope. This instrument photographs the Sun's hydrogen atmosphere at one-minute intervals for seven hours each day.

suddenly released and converted into new forms, such as visible light, radio waves, and particle streams. These electromagnetic phenomena provide the theoretical worker with a new challenge.

Another photospheric feature, of a very different kind, has been receiving much attention: this is the granulation. The Sun's surface, at a temperature of 6000°K, is not of uniform intensity, but is composed of bright granules, averaging about 1000 km. in diameter, with cooler and darker regions in between. The granules brighten up and then subside with a lifetime of the order of five minutes. They are believed to be the tops of convection currents located in the unstable layers below the photosphere which transport the Sun's heat on the last stages of its journey out into space. The small sizes of the granules, combined with the turbulence caused by our own atmosphere, prevent them being photographed satisfactorily from ground-level. In 1956–7, Blackwell and Dewhirst of Cambridge, and Dollfus of Meudon made flights in a balloon to heights of 25,000 ft., carrying an 11-in. telescope which was guided on the Sun. Their photographs of the granules were superior to any which had previously been taken, even from mountain-top observatories. Still better results have been achieved by Schwarzschild in America, who sent an unmanned balloon, equipped with a 12-in. telescope and electronic apparatus for guiding, up to 80,000 ft. His method was capable of resolving elements as small as 250 km. in diameter, but few of these smaller granules have been found. The analysis of such photographs may add greatly to our knowledge of the heat-flow through the photospheric layers of a star.

The chromosphere, or hydrogen atmosphere of the Sun, extends upwards from the photosphere to a height of 15,000 km. Its radiations are monochromatic, and it is best observed in light of the Hα-line of hydrogen or in the H- and K-lines of ionised calcium. This is the region where solar flares occur, which have remarkable terrestrial effects.

Monochromatic pictures of the chromosphere are usually recorded with the spectroheliograph. This is a powerful spectrograph, the entry slit of which is caused slowly to scan the Sun's image. Light of the required emission line, say Hα, is then selected from the spectrum by means of a second slit, and light of this wavelength only falls on the photographic plate behind. If the two slits are synchronised a monochromatic picture is built up. In the spectrohelioscope, rapid scanning, about twenty times per second, is used, and the eye, by the persistence of retinal images, observes a steady image in light of Hα. Both instruments are now being superseded by Lyot filters, as in the Lyot heliograph. Here there is no spectrum: the narrow pass band (about 0·7 Å) of the filter is centred by thermostatic control on the wavelength of Hα (6563 Å) and all other wavelengths in the solar image are removed. Brighter images result and direct photographs with exposures as short as 1/25 sec. can be made.

Above the chromosphere we have the corona, the outer tenuous atmosphere which extends to a distance of many solar diameters, just how far is at present uncertain. The inner corona, where the temperature is 10^6 °K, is a gas composed of highly ionised atoms and many free electrons. The supreme interest of this electron plasma arises from the discovery, made only ten years ago, that it generates and controls the emission of radio waves from the Sun. From the coronal atoms we also receive x-rays which cover a wide band of frequencies.

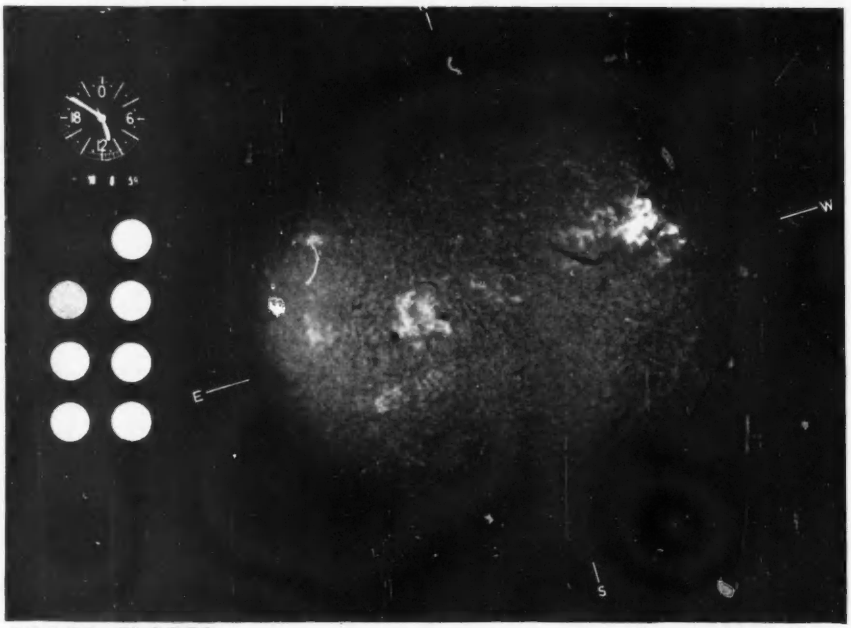


FIG. 4. A Class 3 flare in operation, August 18, 1959, as recorded by the heliograph at the Cape.

SOLAR FLARES

Flares are catastrophic events occurring in the chromosphere and which have immediate effects upon the Earth. They are always associated with active sunspots and they emit radiations of two main types—waves and particles. Both have their influence high up in the Earth's atmosphere. In the right-hand side of Fig. 1 we see that the wave radiation has a travel time of 8·3 min. It consists of three main components. First, we have the x-rays which produce strong ionisation in the D-region. These sudden ionospheric disturbances are observed as "crochets" in the records of the Earth's magnetic field; as fade-outs in the short radio waves which suffer absorption in their passage through the D-layer; and as enhancements of the long radio waves which are reflected from the base of the D-layer. The visible light from the flare can be recorded with a spectrohelioscope, or through a Lyot filter which transmits the Hα-line (Fig. 4). The third component consists of the very long waves which are recorded by radio telescopes.

The particles emitted by a flare travel more slowly—the magnetic-storm particles at an average speed of 1000 miles/sec. These reach the Earth some twenty to forty hours after the flare, always provided that the Earth lies in the line of fire. Newton, who made a statistical discussion of the problem, found that the probability of the particle stream striking the Earth was greatest when the antecedent flare was located near the centre of the solar disc. These particles are the cause of the magnetic-storm disturbances which begin with a sudden commencement that is simultaneous all over the world. They give rise to the auroral luminescence, and their impact upon the ionosphere causes severe disturbance to radio reception.

In addition, we have the cosmic-ray particles. These are charged atomic particles of high energy, travelling at a speed approaching that of light. Since continuous recording of cosmic rays began, five of these sudden bursts have been observed, all associated with outstanding flares on the Sun. The shower most completely recorded was that which occurred on February 23, 1956, when the intensity of the meson component of the secondary radiation suddenly increased by a factor of 2 in the British Isles. In the lower energy end of the spectrum the neutron component showed a sixtyfold increase.

The study of cosmic-ray showers from the Sun raises many fascinating problems. How are they accelerated by the flare mechanism? What are their trajectories through the interplanetary magnetic fields; and how are they related to the normal flux of cosmic-ray particles, the origin of which is still uncertain?

The organisation of the International Geophysical Year provided a splendid impetus to the study of the Sun and its influence on the Earth. The IGY was planned to coincide with a period of sunspot maximum. These maxima occur at intervals of about eleven years, but vary greatly in intensity. As things turned out, the sunspot numbers (Fig. 2) during 1957–8 were 30% higher than in any of the eighteen cycles of activity which had previously been recorded since regular observations began in 1749. Through perfect timing of the IGY enterprise, the current maximum will prove to be the most completely observed in history.

Early in the planning stages it was realised that the Sun must be kept under continuous observation throughout the eighteen months. The Sun was the mainspring of all IGY studies. Therefore we needed the fullest possible information of what was happening at the transmitting end, as well as at the receiving end, of this long line of communications extending over 93 million miles. This meant the provision of solar telescopes, well distributed in longitude and located in the most favourable climates, which would photograph the Sun's hydrogen atmosphere at one-minute intervals.

The organisation became known as the "solar patrol". Some twenty stations co-operated in filming the Sun. Eight were spread out across the U.S.S.R., six across the United States, and one in Hawaii bridged the Pacific gap between Mount Wilson and Tokyo. The British National Committee contributed one of these Lyot heliographs, of advanced design, to assist the solar patrol. This instrument was set up at the Royal Observatory, Cape of Good Hope. There, the hours of bright sunshine are, on the average, twice as

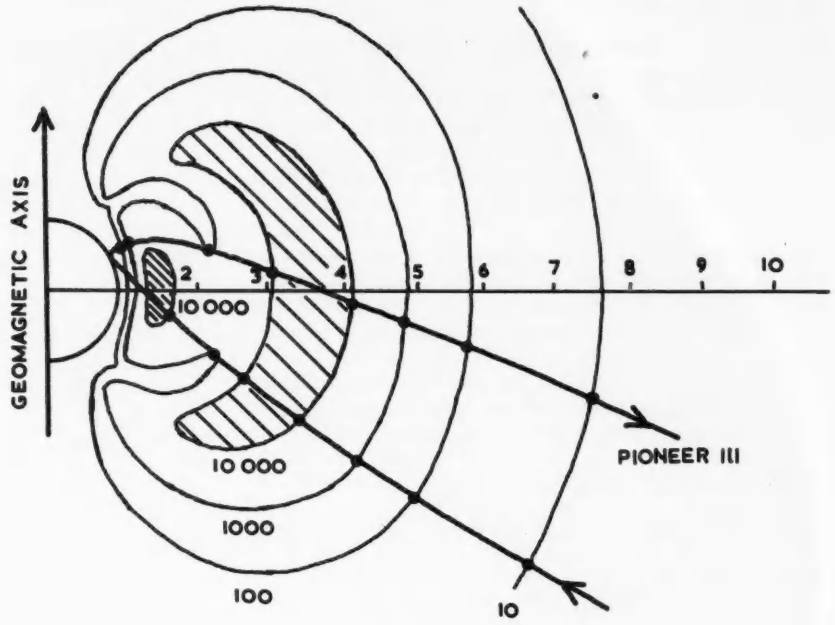


FIG. 5. The van Allen radiation belts of high-speed particles trapped within the Earth's magnetic field. The contour lines show the counting rates per second of the Geiger-Müller tubes in satellite 1958ε and in lunar probe *Pioneer III*. Distances are given in terms of the Earth's radius ($R = 6400$ km.).

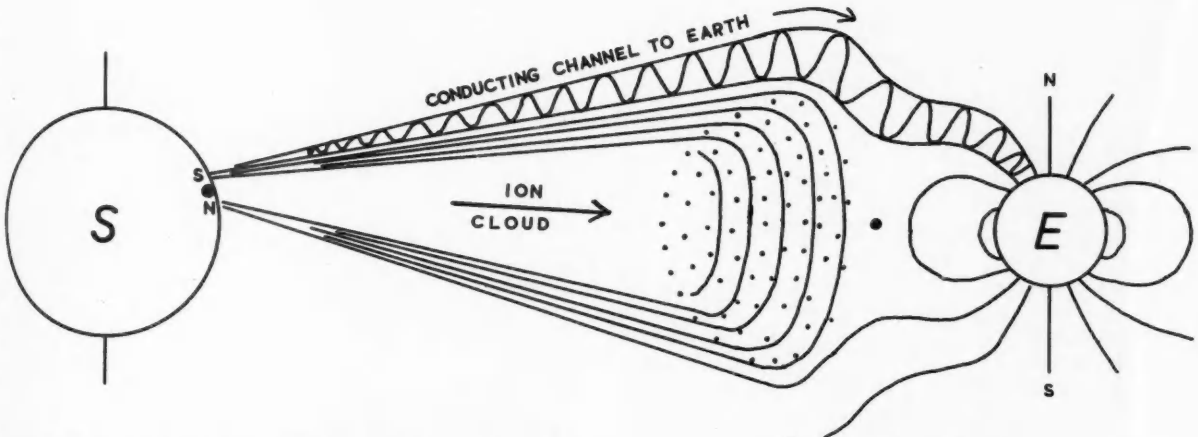


FIG. 6. Cloud of ionised particles blown out from the Sun which extends the lines of forces of a sunspot field to the Earth's neighbourhood. Temporary linkages enable particles to spiral directly from Sun to Earth.

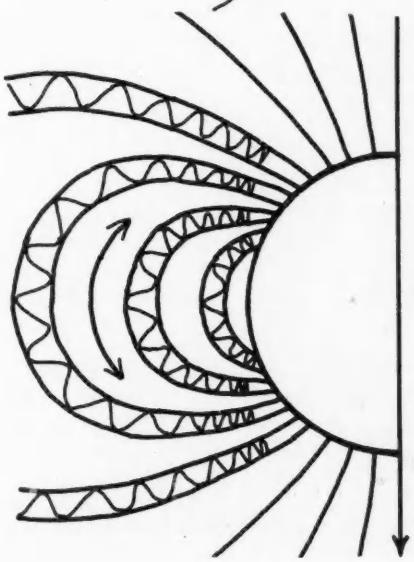


FIG. 7. The spiral motion and the N.–S. oscillatory movement of a charged particle trapped within the Earth's magnetic field.

great as anywhere in the British Isles. The heliograph (Fig. 3) is electronically guided on the Sun; it regulates its exposure time according to the state of the sky, and makes its exposures automatically without the need for an observer in constant attendance.

As a result of these efforts, splendidly detailed records of solar flares and prominence activity have been contributed to the data centres of IGY. The final figures show that during the eighteen months the Sun was under continuous observation for more than 90% of the possible hours, so that little activity of importance can have been missed. The main results of this co-operative enterprise will be published in the *Annals of the IGY*. It is also gratifying to know that many of these instruments, provided at great cost, will remain in operation for a number of years in furtherance of our studies of solar-terrestrial relations.

ROCKET AND SATELLITE RESULTS

The many launchings of rockets and satellites during the IGY have initiated types of recording which will be of immense value in the study of solar-terrestrial effects.

Photographs of the Sun's disc can now be obtained from regions virtually above the atmosphere and in wavelengths that have been hitherto unobserved. The first well-defined picture of the Sun in Lyman α-light (1216 Å) was taken on March 13, 1959. This photograph (see DISCOVERY, 1959, vol. 20, No. 7, p. 283) was secured with a grating spectrograph and camera carried to a height of 170 km. in an *Aerobee Hi* rocket. The instrument was guided by a photoelectric Sun-follower.

Lyman α-radiation is now considered to be the cause of the ionisation of NO molecules at a height of about 80 km. above the Earth, which gives rise to the supply of free electrons forming the *normal* D-layer.

The picture showed that the Lyman α-emission regions on the solar disc coincide very closely with the bright plages which we observe in Hα-light, though they are considerably greater in extent. As is well known, the Hα-plages mark out the regions of sunspot activity, and so we may expect that the Lyman α-regions will vary in area and intensity, showing a similar dependence upon the eleven-year period of activity. We owe this fine achievement in extra-terrestrial astronomy to the U.S. Naval Research Laboratory in Washington.

In 1957, as part of its IGY programme, the Naval Research Laboratory also launched a series of rockets into the D-region (60 to 90 km.) in order to detect the ionising radiation emitted by solar flares. As noted above, when a flare occurs the ionisation in the D-region—the lowest of the ionospheric layers—undergoes a sudden increase. It is these extra electrons which cause, by their absorption, the radio fade-outs observed at such times. The facts had been understood for some twenty years but the causative radiation was unknown. The rockets (Fig. 8.) were equipped with detectors for Lyman α and for X-rays of various wavelengths, and the launchings were made as soon as major flares were signalled in operation by the Climax and Sacramento Peak solar stations. The rocket measurements, telemetered back to ground, showed that the D-region was absorbing a powerful flux of X-rays in the wave-band 1 to 8 Å. On the other hand, no large increase in Lyman α was recorded.

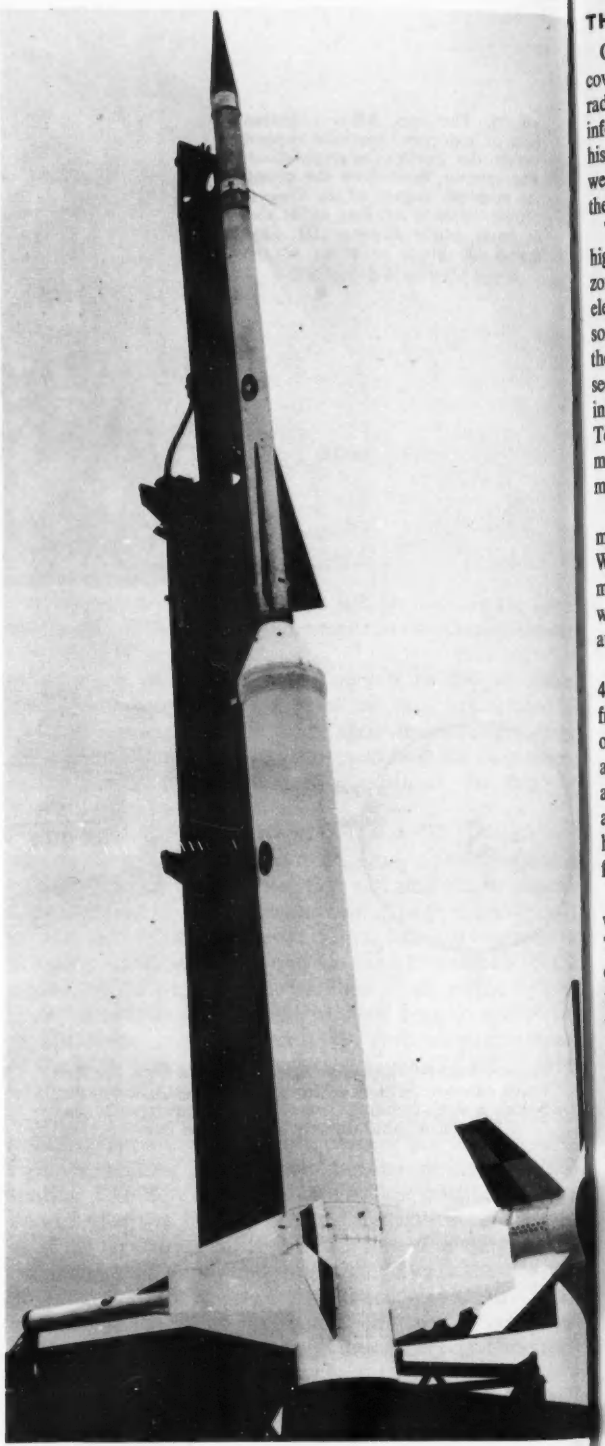


FIG. 8. A two-stage solid propellant rocket *Nike Asp*, as used by the U.S. Naval Research Laboratory. These rockets are kept at the ready and are launched into the D-layer when a major solar flare is observed. They record the ionising radiations from the flare which are responsible for the short-wave radio fade-outs.

(Official U.S. Navy photograph released by the Department of Defense, Washington, D.C. September 29, 1959)

THE VAN ALLEN RADIATION BELTS

One of the most exciting and potentially valuable discoveries has been that of the belts of intense particle radiation surrounding the Earth. The most complete information about these regions comes from van Allen and his group in the United States, the recordings of which were made with shielded Geiger-Müller counters carried in the satellite 1958ε and in the lunar probe *Pioneer III*.

There are two distinct and widely separated zones of high intensity, as shown in Fig. 5 (after van Allen). The two zones contain fast charged particles, mainly protons and electrons, with energies ranging from some tens of KeV to some tens of MeV. Within these regions (shown shaded in the diagram) the counting rate exceeded 10,000 per cm.^{2}/sec., and one can observe the rapid fall-off of intensity with increase of distance between $4R$ and $10R$ (R=6400 km.). To obtain the three-dimensional structure of the belts one must imagine the diagram rotated about the Earth's magnetic axis.

The existence of particles trapped within the Earth's magnetic field raises all sorts of fascinating problems: Where do they originate? What are the trajectories of their movements within the field and how are they injected? In what way are they associated with geomagnetic storms and aurorae?

The inner belt, extending in thickness from 1000 to 4000 km. above the Earth, may receive its energetic particles from cosmic-ray disintegrations which occur near the top of the atmosphere and diffuse outwards. The outer belt, at a distance of 3 to 4 Earth radii, is much more extensive and has its northern and southern cusps above the two auroral zones. It seems most probable that the particles here are injected from streams which have been blown out from the Sun.

We have seen that there are two types of particle stream which can reach the Earth following an intense solar flare. The first, and rarer of the two, is the burst of primary cosmic rays which arrives within the first hour after the flare; the second is the stream of magnetic-storm particles which gives rise to the geomagnetic disturbances and auroral displays one or two days later. There is much evidence that all this material is blown out from a limited region in the solar chromosphere and corona immediately above the flare. In such a region there will be a strong magnetic field provided by the associated sunspot group. The blow-off particles, being largely ionised, must carry the lines of force of the sunspot magnetic field with them far out into the solar system, so that the lines of force eventually envelop and "catch on" to the terrestrial field (Fig. 6). So long as this magnetic linkage exists between the sunspot and terrestrial fields, whatever charged particles are available at the solar end, can spiral freely along the lines of force from Sun to Earth.

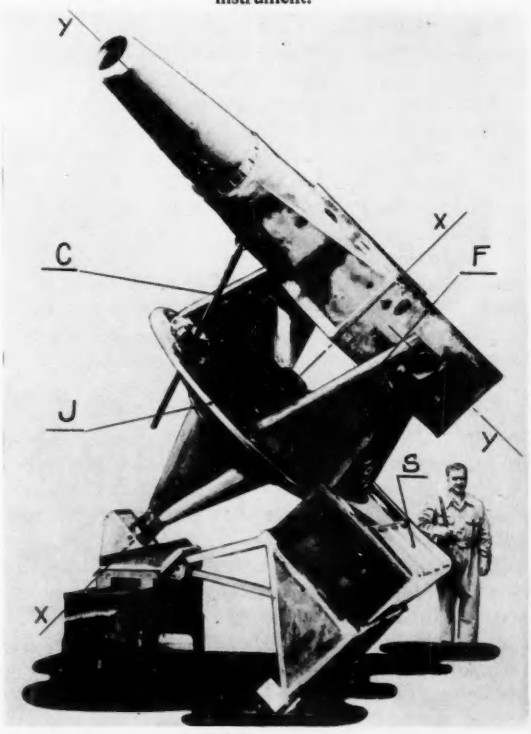
The resultant violent distortions of the Earth's field allow the particles to enter the outer van Allen belt. The more energetic particles will succeed in reaching down to atmospheric levels in the auroral zones and will cause the auroral luminescence. Those with less energy, perhaps 1000 times more numerous, become trapped in the van Allen region without immediately reaching the atmosphere. Here they remain for periods possibly of several weeks after the main disturbance has passed on beyond the Earth's orbit and the terrestrial field has resumed its normal dipole shape.

The subsequent history of the trapped particles has been investigated by Gold. Since they are charged, the particles must spiral along the terrestrial lines of force. A proton of 10 MeV energy would have a radius of gyration of a few kilometres at a height of 3000 km. above the magnetic equator. Towards the north and south ends of a line of force the particle travels into a converging field, and when the pitch angle of its spiral motion increases to 90° it is reflected. Rapid oscillations thus set in between the reflexion points in the two hemispheres (Fig. 7): the time of oscillation is of the order of 1 sec. The particle continues its N.–S. oscillations so long as it does not enter the atmosphere. In addition, a drift in longitude takes place due to the vertical gradient of the Earth's field, electrons drifting eastwards and positive ions westwards. Irregularities in the dipole field may also cause a drift and diffusion in height.

Because of the complexities of these motions it is impossible to say what is the lifetime of the particles within the belts. Many more measurements of the particle flux will be needed. It will be of great interest, for example, to establish its variability with the day-to-day changes in solar activity and on the longer time-scale of the eleven-year cycle.

Meanwhile, we can say that this altogether unexpected product of rocket research has opened up a most exciting chapter in the study of Sun-Earth relationships.

FIG. 9. The mounting of a new coronagraph, built for the Pic du Midi Observatory (9400 ft.) by the Tarbes Arsenal. *S* is the fixed support with driving mechanism for the equatorial head, *J*. *F* is the fork-mounting which rotates about the polar axis, *XX*. *C* is the rack and pinion for varying the elevation. *YY* is the optical axis of the instrument.



THE EARTH-MOON SYSTEM

GILBERT FIELDER

For more than three millennia man has been asking fundamental questions about the Earth and the Moon. Rocket research is now providing precise information about their shapes, atmospheres, and interiors.

Ever since G. H. Darwin made the suggestion that the Moon was formed from the outer parts of the Earth and was flung off from this parent planet, the idea has become very popular. Fifty years ago, however, F. R. Moulton published a paper in which he demonstrated that it was extremely unlikely that the Moon had come from the Earth. The popular conception—unfortunately still widely prevalent—is that the Moon originated in the basin of the present Pacific Ocean. If the Moon had exposed deeper rock-layers on the Earth, after having been stripped from it, the bottom of the Pacific Ocean would be expected to differ in composition from the bottoms of the other oceans of the Earth. We now know that no such differences appear to exist: the floor of the Pacific ranks as typical amongst the other great ocean bottoms, and we must turn elsewhere to find the place of origin of the Moon.

Although no scheme of the origin of the planets proposed so far has been sufficiently all-embracing to meet with general approval, the majority of astronomers now believe that the Earth and the Moon, like the other planets, were formed separately. Each one is thought to have accumulated from debris which once formed a vast, turbulent cloud, and that the central regions of this cloud collected to form the Sun.

H. C. Urey has studied the chemical composition and physical structures of meteorites and has been led to draw a powerful inference: objects in the early solar system condensed from a dust cloud. These objects were at least as big as the Moon (a quarter of the size of the Earth); they were heated, cooled, and fragmented, and new objects accumulated from the fragments. Urey's results demonstrate that the past history of the solar system is complex, and this makes it difficult to investigate the origin of the planets and their natural satellites. The Earth and the Moon probably condensed separately but, if they have different compositions, they may not have condensed at the same time. It is also probable that the Moon has always assumed a position close to the Earth, the two bodies revolving round their common centre of gravity.

THE SHAPE OF THE EARTH AND THE MOON

So we may think of the Earth and the Moon as the products of the accumulation of solid objects at neighbouring points in space: both bodies were probably formed "cold".

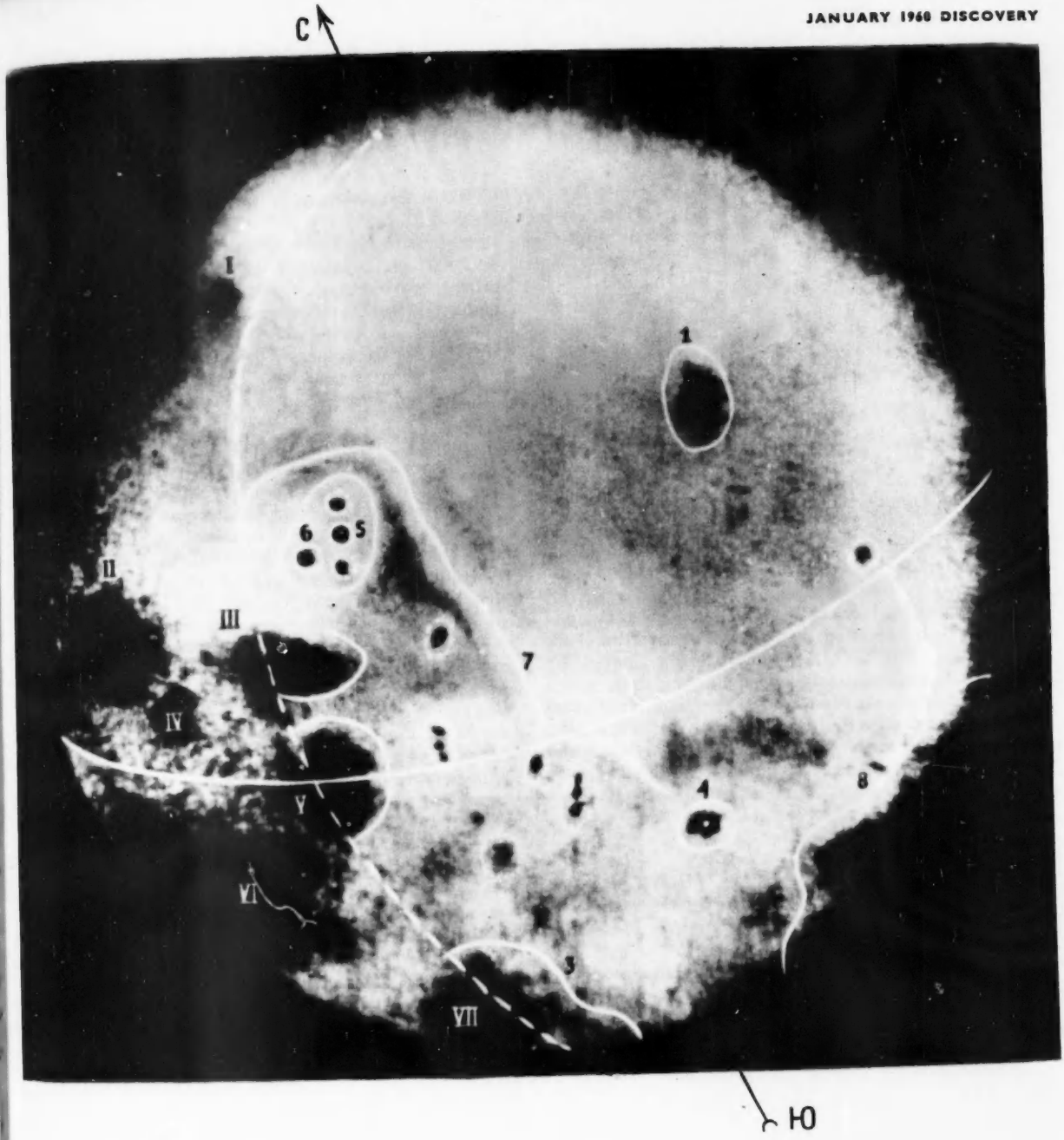
Solid rocks can flow under their own weight as well as liquids (but solids take very much longer than liquids to flow a given amount), and even the Moon, where the surface gravity is only one-sixth of the Earth's, approached the form of a sphere by exerting sufficient pull on the last objects which it accumulated. Any high protuberance on the sphere would be pulled down by its own weight.

It is common knowledge that the Earth is not a perfect sphere. This is largely because of its axial spin, which causes the equator to bulge, with the result that the distance between the poles of the Earth is less than the equatorial diameter by some 27 miles. At present, the shape of the Earth is being re-examined with the aid of gravity-meter readings taken over land masses and ocean bottoms. The ocean floors are poorly charted—partly because of the difficulties of obtaining submarines to be used for work of this nature—but in recent years great sub-oceanic mountain chains and trenches have been located.

The Moon rotates on its axis only once in a lunar month (which means that one hemisphere of the Moon is permanently averted from the Earth), and the amount by which this rate of spin causes the Moon to deviate from a sphere is scarcely measurable. In spite of this, the Moon is not quite spherical. There are, of course, high mountains just as there are on the Earth but, quite apart from these, there is some evidence of a general bulge on the earthwardly turned face of the Moon. The magnitude of this bulge appears to be only of the order of one mile.

Of course, we are not yet able to carry a gravity-meter across the Moon's surface and measure its shape that way; the manner in which the bulge on the Moon has been measured is altogether different. A small, sharply defined spot, or crater, on the Moon is selected, and its position is recorded with reference to the apparent centre of the Moon's disc. Then, when the Moon rocks round through several degrees (this rocking is occurring slowly all the time and is called the *libration* of the Moon), the position of the same point is remeasured. From the measurements, it is possible to find the distance of the point from the centre of the Moon. The problem is not as simple as it may sound, and the accuracy of available measurements is low, so that the results do not always indicate that there *is* a bulge. It is possible to improve the situation without leaving the Earth, but improved results on the shape of the Moon should accrue from a suitably instrumented satellite.

Artificial satellites of the Earth have already provided estimates of the degree of polar flattening of our planet, and these estimates are better than those of more conventional methods. The reason is that a satellite in orbit round a planet moves, in the absence of an atmosphere, according to the laws of gravitation. If there is an excess of matter at one position of the planet, the satellite will accelerate towards it. The observable effect on the motion of the satellite may be only very small, but the orbits of Earth satellites which make large angles with the equator are markedly affected by the equatorial bulge. Because of this protuberance of the Earth, the orbital plane of a satellite rotates about the Earth's axis in a direction opposite to that of the satellite itself, and the axes of the satellite's orbit



THE RUSSIAN LUNAR PHOTOGRAPH

October 1959 marked a great advance in space research. For the first time it became possible to photograph regions of the Moon always turned away from the Earth, and so previously unknown. The photograph was taken on October 6 from the Russian vehicle *Lunik III*, and transmitted back to Earth on October 18, after having been developed and processed inside the *Lunik* itself.

Since the vehicle was approximately between the Moon and the Sun, the photograph is a "high-light" one; moreover, the definition, though amazing under the circumstances, is poor by normal standards, and only major features are shown. The new regions of the Moon are—as expected—similar to the old, and probably just as rough, though major *maria* or seas appear to be absent.

The continuous line represents the lunar equator. Solid lines round objects indicate features whose positions are established; dotted lines round objects show features whose nature is dubious. To the left of the curved broken line appear features visible from Earth; Mare Humboldtianum (I), Mare Crisium (II), Mare Marginis (III), Mare Undarum (IV), Mare Smythii (V), part of Mare Foecunditatis (VI), and Mare Australe (VII). Features on the new regions include a dark area, the Moscow Sea, which may be a small *mare* (1), with the Bay of Astronauts (2). (3) is a continuation of Mare Australe. (4), (5), and (6) have been named Tsiolkovskii, Lomonosov, and Joliot-Curie respectively; they may be craters. (7) is said to be a range of peaks, the Sovietsky Mountains, and (8) another *mare*, the Dream Sea.

rotate in the plane of the orbit. Satellite tracking stations are being used to measure these changes.

ATMOSPHERES AND INTERIORS

The Earth is massive enough to hold on to a relatively dense atmosphere, consisting now of nitrogen and oxygen, with small amounts of argon, carbon dioxide, and traces of many other chemicals. Atmospheric constituents have been examined at altitudes of up to 20 miles by means of instrumented balloons, and for many years rockets have been used for sampling the air at higher altitudes. The Moon, only one-eightieth as massive, cannot retain any but the heaviest gases, such as stable hydrogen sulphide, krypton, and xenon. No atmosphere enveloping the Moon has ever been detected. But N. A. Kosyrev appears to have observed and recorded a brief, localised gaseous emission from the centre of the crater Alphonsus.

That the Moon has virtually no atmosphere and differs so much, in this respect, from the Earth, is one of the factors determining the different evolutionary paths followed by the surfaces of the two bodies. Thus, erosion of the surface features caused by water and wind is absent on the Moon, but small meteorites, which disintegrate in the Earth's atmosphere, erode the surface of the Moon.

Seismic waves passing through the deep layers of the Earth indicate that, about half-way between the surface and the centre, there is a sharp change in the properties of the materials: the Earth has a core which acts like a liquid. We know that, in deep mines, the temperature increases as one descends, but there are reasons to believe that this increase of temperature does not proceed uniformly to great depths, and that even the centre of the Earth is probably not hotter than a very few thousands of degrees Centigrade. If the Earth originated in a cold state, how did it gain its heat? In accessible parts of the crust, we find samples of radioactive materials which decay naturally into other chemicals and, in the process of so doing, liberate heat. Unfortunately, we have no positive knowledge of the distribution of radioactive materials inside the Earth, and the same applies to the Moon. We can analyse meteorites for radioactivity and, if we assume that the Earth and Moon are agglomerates of meteorites of similar type, we can set probable limits to their internal temperatures.

Volcanic phenomena indicate that at least isolated pockets of molten rock exist beneath the surface of the Earth, but the temperature of lava really tells us little about the general state of matter inside the Earth.

On the Moon, there are many chains of craters which can only be explained as having originated from within the Moon itself. It is true that a string of meteorites could collide with the Moon to produce a row of craters. Such an alignment of particles would itself be rather improbable, but the main reason why we can rule out that origin for many of the lunar crater chains is that they frequently run parallel to other linear selenological features (*selenology* applies to the Moon as *geology* applies to the Earth). Thus, there are many mountainous striae on the Moon which form a chopped sequence of roughly parallel distortions of the rocks, often running for many hundreds of miles across the surface (Fig. 4). Trench-like features, called *rilles*, are often associated with these distortions, and crater chains sometimes lie in the axis of a rille. The chances that such craters have been produced by the impact of meteorites are negligibly small. These chain craters are not at all like volcanoes; far from assuming the form of a cone, each crater takes the form of a shallow, saucer-type depression, a 3-mile crater being, perhaps, only 200 yards deep. No vast differences have been detected between these craters in chains and the rest of the lunar craters, many of which, at least, must be of impact origin. The reason is not difficult to find if the craters were all moulded by explosions. The Moon encounters meteorites at velocities often as large as 50 miles/sec. and, in such collisions, the meteorites would not penetrate much more than their own diameters before the compressed rocks would vaporise and explode to throw aside volumes of rock debris vastly greater than the volumes of the original meteorites. Could the chain craters have been excavated explosively if they are igneous in origin? This seems to be quite possible. Faults may be observed in the Moon's surface. Molten rock reaching the surface via concealed fractures would lose heat to space fairly quickly. In any part of the melt which crystallised rapidly, as a consequence of this cooling, the internal pressure would rise sharply and could initiate an explosion, relieving the excess stress. Such a process would produce craters similar in form to those of impact origin.

Again, this reasoning, even if correct, merely indicates that there are at least localised heat sources within the Moon. It tells us nothing about the temperature at, say, the centre of the Moon. Certainly, the Moon cannot have a large, liquid core, like the Earth's, for the lunar surface-irregularities require a strong base to support their weight and such a core would be revealed by the manner in which the Moon moves. We do not know if the Moon was ever completely molten, and until we are able to perform more intimate investigations there are bound to remain uncertainties in our theories.

MAPPING THE EARTH AND THE MOON

Large areas of exposed land on the Earth remain uncharted, to say nothing of our scanty knowledge of the ocean floors. In a sense, it is easier to map the Moon. On the terrestrial continents and islands, standard positions may be measured fairly accurately by observing the stars, and elevations may be surveyed by trigonometric methods.

About 70% of the averted hemisphere of the Moon has been photographed by the Russians, but details are not clearly defined in the first pictures which have been released and the positions of features can be determined only very approximately. However, the position of *any* point on the Moon is not known with great accuracy. The measurement of the position of many points on the Moon's surface was performed at the beginning of the present century by J. Franz and S. A. Saunder, and errors in their measured longitudes and latitudes were sometimes as large as one mile of lunar surface even for the central regions of the Moon's disc, where the errors are least. Little has been done since then to improve the situation, partly because professional astronomers mostly turned their attention to important stellar and galactic research and partly because of the complexity of the problem and the large amount of labour involved in work of this nature. Now that we have fast electronic computers, this last point may no longer be used as an excuse to avoid making fresh, original measurements, but there is still the practical problem of finding financial support for this work.

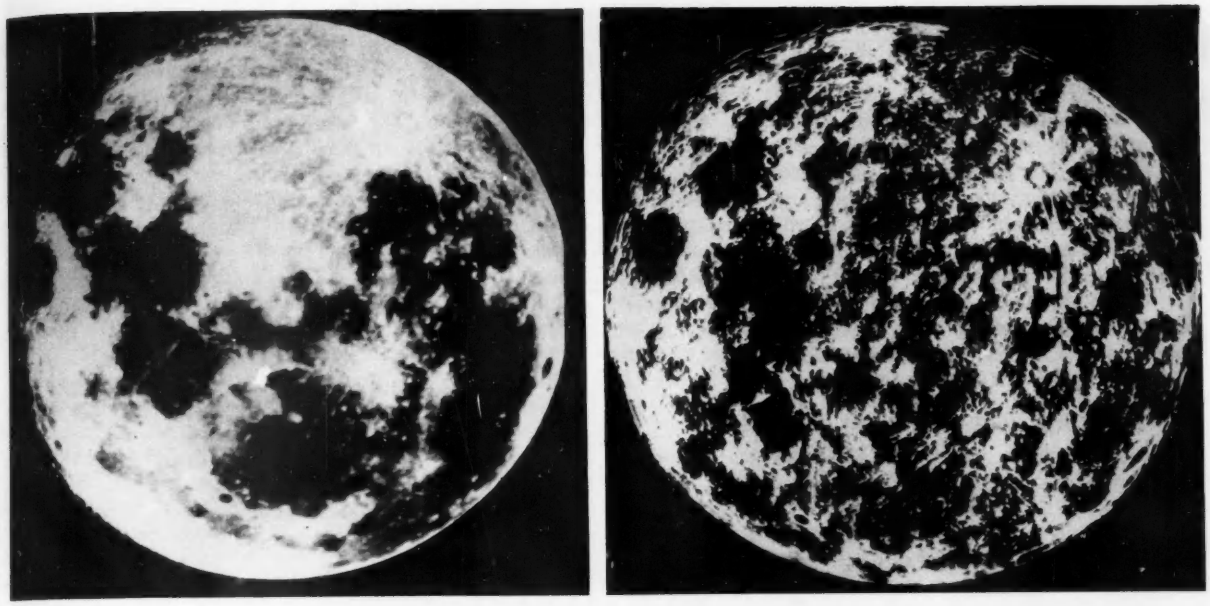
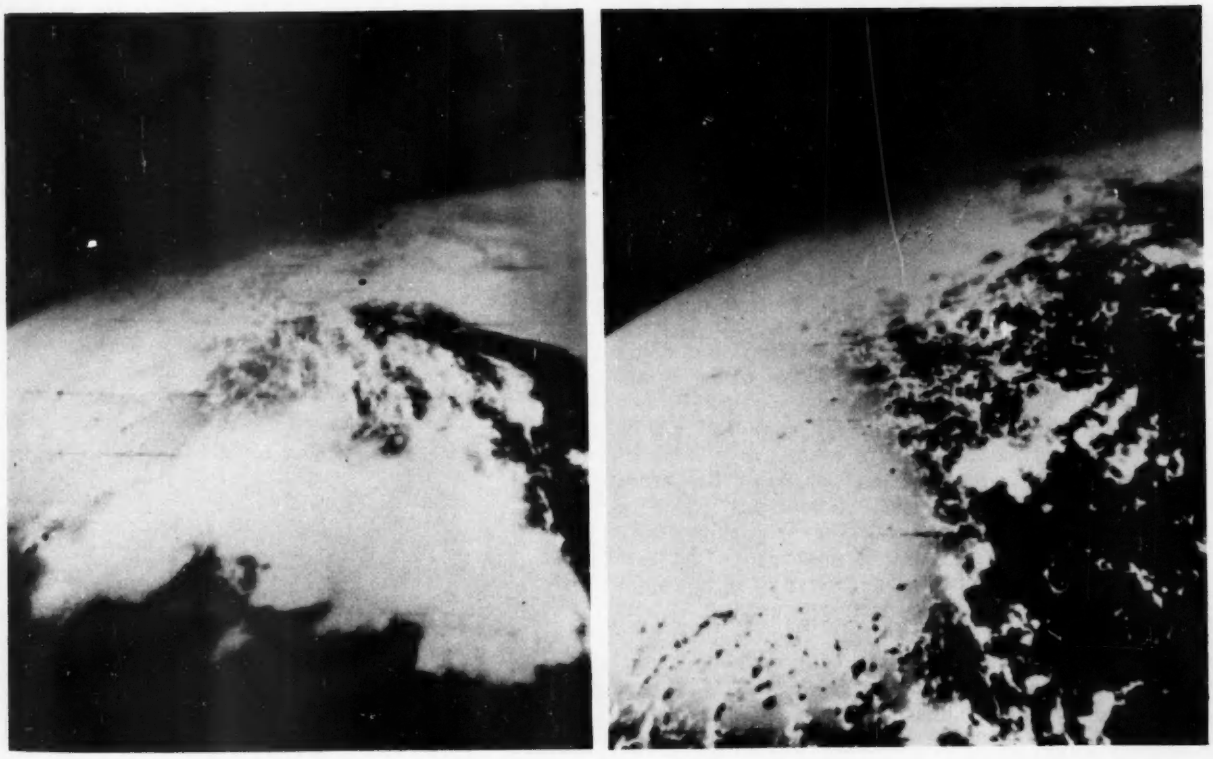


FIG. 2. Television camera gives detailed picture of Moon surface. New, detailed pictures of the Moon and planets are being taken with a super-sensitive television camera operating through a telescope by astronomers in the United States. The opto-electronic telescope system, nicknamed "Cateye" and developed at the Wright Air Development Center in Dayton, Ohio, is now in operation at the Weaver Observatory in Springfield, Ohio. The electronic photo (*right*) is actually a composite of over 200 pictures taken through the television pick-up tube. The photo on the left is a conventional picture of the Moon.

(By courtesy of the U.S. Information Service)

FIG. 3. Views of the Earth's cloud coverage west of Antigua Island.

(By courtesy of the U.S. Information Service)



Why should we want more accurate positions of points on the lunar surface? All measurements of the altitudes of points on the Moon depend on a knowledge of the positions. If the positions are in error, so are the computed altitudes based on them. When mountains are being measured, it is true that a positional error usually reflects as a much smaller error in a measured height, but the errors increase at an alarming rate as one approaches the edges of the Moon's apparent disc. There is, of course, no sea level to act as a datum for altitudes, and the height of an elevation can only be specified with respect to a certain, estimated position lower than the top of the elevation. A very practical reason for wanting more accurate positions than are now available is that they will provide the basis of maps to be used by the first lunar explorers.

WHAT THE FUTURE MAY BRING

Let us turn, now, to see how the future will transform our knowledge of the Earth-Moon system. To specify the past history of the Moon with some confidence requires, for one thing, new observations of the positions of points on the lunar surface. From these positions, the shape of the Moon may be computed and compared with its shape derived from theories of its motion and composition. Secondly, new observations of the position of the Moon itself, with respect to background stars, are required to provide more direct information of the motion of the Moon with respect to the motion of the Earth. Special cameras, constructed for use during the International Geophysical Year, are being used for this purpose.

Improvements on the old positional measurements are quite possible simply by virtue of present-day improved techniques. However, all measurements made from even the highest observatories of the Earth necessarily suffer errors as a result of the unsteadiness and varying intensity of a light-beam traversing the atmosphere. These effects, which the astronomer classifies as "seeing" and "transparency", may be removed altogether if observations of the Moon are made from artificial satellites above the atmosphere. There is the difficulty—recently overcome by the Russians—of pointing the camera or other recording device at the Moon and accurately knowing the position of the camera-bearing satellite at the instant of each record, but a bigger difficulty tending to offset the advantages of having no atmospheric effects to contend with is to pass the observational data back to Earth in a suitable form. The Russians used radio waves, but atmospheric effects were introduced again, since the radio waves passed through the disturbing ionosphere. However, experts seem to believe that the complicated "re-entry problem" will be satisfactorily solved in the near future: if it becomes practicable to return an object undamaged to the Earth's surface, information stored on a photographic plate, for example, could be returned to Earth in the satellite itself.

There are less direct ways of investigating the past history of the Earth-Moon system. The origin of terrestrial magnetism is far from being completely understood, and the rotating, liquid-type core of the Earth undoubtedly holds many of the clues which are required to unravel the complicated picture of the magnetic field which has been constructed from observations at the surface of the planet. If we knew more about the Earth's core, we would know more about the magnetic field. Conversely, intensive studies of the magnetic field, not only on the surface of the Earth but also for as far as is practicable out into space, will tell us more about the core of the Earth. It is believed that the Moon has no liquid core, and hence it is important to establish whether or not the Moon has a magnetic field of its own.

Aurorae have their origin in electrically charged particles which are emitted by the Sun. These corpuscles have their paths bent round in the Earth's magnetic field, and they interact with air particles, producing luminous phenomena. If the Moon had a magnetic field of strength at all comparable with that of the Earth's, lunar aurorae would be visible in the polar regions of the Moon—on the surface, in the absence of an atmosphere. Because he has detected no lunar aurorae, N. A. Kosyrev concluded in 1956 that the Moon does not possess a magnetic field.

The Russian *Lunik II*, which reached the Moon on September 13, 1959, sent back radio pulses which have confirmed this. Geophysicists may be to some extent reassured that the core of the Earth plays an important part in terrestrial magnetism, and astronomers may feel that their speculations on the absence of a core in the Moon have possibly been correct. A better understanding of the motions, the forms of the surfaces, and of the nature of the interiors of the Earth and the Moon is very much to be desired if we are to trace the past history of the system with some accuracy.

To send automatic instruments to land on the Moon is evidently a dream of the near future. To send men there is perhaps looking many years ahead, and it is difficult to see how some experiments could be conducted without human intervention on the spot.

One is tempted to ask: What are the rocks made of? What proportion of radioactive elements do they contain, and what is the rate of loss of heat from the interior? Does the surface of the Moon consist essentially of rock debris, and how much rock dust is there in different parts? Do the rocks show *any* trace of magnetism? How deep does one have to bore before coming to solid rock? What do seismic waves, travelling through the Moon, tell us about its internal constitution? Are there negative or positive gravity anomalies over the mountains? Is there any trace of atmosphere and what is its composition? At what rate is the Moon bombarded by meteorites? What lies in the still unphotographed 15% of the Moon's surface?

We already have provisional answers to these questions; questions which man started asking three and a half centuries ago when he first turned a telescope to the Moon. Research is intensifying, and it may not be too long before the answers cease to be simply provisional.

FIG. 4. This photograph, taken by the writer at the Pic du Midi Observatory, shows the central portion of the Moon's disc; the big crater at the bottom is Manilius (width about twenty-four miles). Notice the mountainous striae, running from bottom right to top left, and the prominent rilles at the top. The rille on the right has a crater chain set in its axis.

MERCURY, VENUS, AND MARS

PATRICK MOORE, F.R.A.S., F.R.S.A.

Director of the Mercury and Venus Section of the British Astronomical Association (Secretary of the Lunar Section, 1945–55)

In the next stage of the space probe, rockets will be sent to the inner planets. Venus is particularly difficult to study from the Earth because it is surrounded by an impenetrable atmosphere, and our instruments are not powerful enough to provide conclusive information about Mars and Mercury.

The direct exploration of space has already begun. Instrumented rockets have been sent to the Moon, and plans to send probe vehicles to Mars and Venus are already being made.

It is hardly surprising, then, that there is a new surge of interest in planetary astronomy. Professional workers as well as amateurs are doing all they can to find out more about surface conditions on our neighbour worlds—particularly with regard to Mars and Venus, which will certainly be our first space-targets apart from the Moon.

Mars is the more promising of the two, and in some ways it is not so very different from the Earth. It has an atmosphere, it has a certain amount of water, and probably it has plant life. Neither are the temperatures hopelessly unfavourable; admittedly the nights are very cold, and would send a thermometer down to something like −100°F, but on a midsummer day on the equator the temperature may rise to over 70°F.

Mars is farther away from the Sun than we are; its mean distance from the Sun is 141½ million miles, and the sidereal period or "year" is 687 days. The Martian "day" itself is, however, only half an hour longer than our own. The diameter of the globe is 4200 miles, and the mass is only one-tenth of that of the Earth. This means that the escape velocity is only 3·1 miles/sec. instead of 7 miles/sec., as for the Earth.

The main trouble about studying Mars is that we have to wait for the most favourable periods. Oppositions—when the Sun, the Earth, and Mars are roughly lined up, with the Earth in the mid position—occur at intervals of about 780 days, and the next one is due at the end of December 1960; but not all oppositions are equally favourable, because the orbit of Mars is markedly elliptical. In 1956, for instance, Mars approached us to within 35 million miles or so, but it will not be so close again until 1971. Moreover, its small size means that even when it is best placed, little useful research can be carried out except with the help of powerful instruments.

THE SURFACE OF MARS

Small telescopes are able to show the broad features; so let us begin with the white caps which cover the Martian poles. The old observers regarded them as snowfields similar to those of Earth, and watched them as they shrank steadily during the spring of the hemisphere concerned; during Martian summer they became very small, and sometimes the southern cap disappeared completely for a while.

It was natural enough to regard the caps as snowy, but other ideas were put forward, and some astronomers suggested that the caps might be due to "dry ice"—solid carbon dioxide. This theory did not sound particularly reasonable, but it was quite widely supported during the first part of the 20th century. Finally the problem was cleared up by G. P. Kuiper, working in the United States. By spectroscopic methods, he proved that the caps were definitely made up of some icy or frosty substance, and the solid carbon dioxide theory died a painless death.

Yet the caps are not truly analogous to the polar snowfields of Earth. Antarctica and North Greenland are covered with an immense thickness of ice; the Martian caps are certainly less than a foot deep, and may be nothing more than a surface layer of hoar-frost. It may even be wrong to say that they "melt" as they shrink in the springtime; they may well sublime, that is, pass directly from the solid to the gaseous state.

The dark patches on Mars have been under observation ever since the year 1659, when they were first recorded by the Dutch astronomer Christiaan Huygens. Their outlines seem to be more or less permanent, and detailed surface maps have been drawn up; the most conspicuous patches, such as the rather V-shaped Syrtis Major (formerly known by the more picturesque name of the Hourglass Sea), may be seen with a modest telescope when Mars is near opposition. Unfortunately, we have as yet no definite proof as to what they are. They are certainly not seas, since Mars is painfully short of water, and even moderate lakes are hardly to be expected. It is more likely that they are due to vegetation.

The indirect evidence in favour of this idea is decidedly strong. As the polar caps shrink with the warmer weather, the adjacent dark patches seem to become harder and sharper, as though the plants were being affected by the arrival of moisture; such behaviour is difficult to explain except on the theory of living plants. Moreover, we know that dust-storms occur on Mars, and that dusty material is blown across the dark areas from the neighbouring deserts. If the dark areas were not made up of stuff which could grow, and so cover the dust, the whole planet would soon assume a monotonous reddish-ochre hue.

During the last few years, Russian astronomers have paid a great deal of attention to the problem of possible plant life on Mars. Their results are in good agreement with those of workers in other countries, and the best we can say at the moment is that although we have no conclusive proof, the existence of vegetation there is highly probable. Other theories have been put forward—it has even been suggested that the dark areas are due to ash ejected from powerful volcanoes—but after all, it is reasonable enough to expect life on a world such as Mars, which is by no means hopelessly unfriendly.

Needless to say, we can have no real idea of what the Martian plants are like, but we can at least speculate. We cannot hope to find anything so advanced as a tree, or even a flower; it is important to remember that the atmosphere

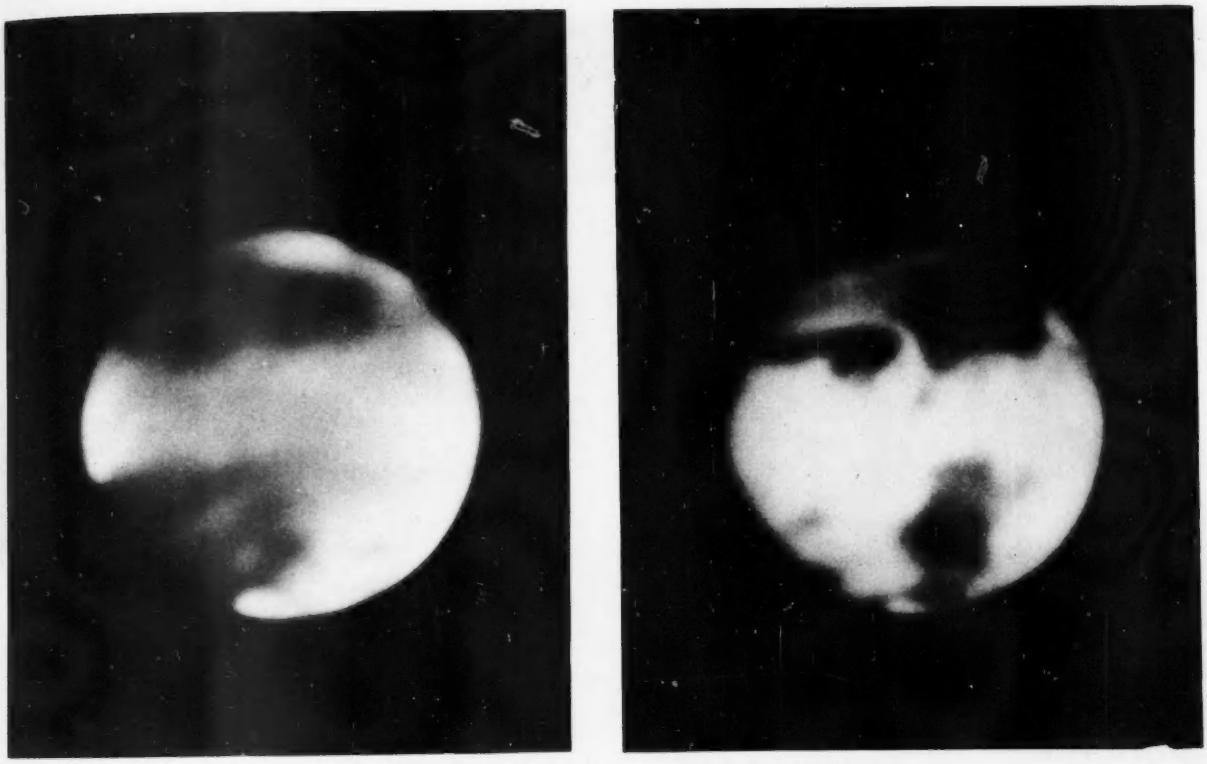


FIG. 1. Mars, photographed with the 200-in. reflector at Palomar.
(Reproduced by courtesy of Mount Wilson and Palomar Observatories)

is thin and dry, and that moisture is scarce. More probably the plants are no more highly developed than our lichens or mosses. This is not to say that they are closely similar to Earth-type lichens or mosses; questions of this sort will not be cleared up without the help of probe rockets. Neither can we tell whether any underground water supplies are available.

The reddish-ochre areas are commonly termed "deserts", but here again there is no real analogy with our Sahara. There can be no sand on Mars, and it is more likely that the characteristic hue is due to coloured minerals such as felsite or limonite.

Mars has an appreciable atmosphere, but there seems to be very little free oxygen; water vapour must be present, but is not abundant. Carbon dioxide has been detected by means of the spectroscope, but it seems that the bulk of the atmosphere is likely to be composed of nitrogen. It is fair to say that although the Martian mantle is not poisonous, it is quite unbreathable so far as Earth-type animals or men are concerned. This is not only because of the paucity of oxygen and water vapour. The atmosphere is so thin that even were it made up of pure oxygen, we would still be unable to breathe it.

Mars has always been regarded as a possible abode of life, and fifty or sixty years ago it was commonly believed that signs of activity were visible there. Certain thin, straight lines, known popularly as "canals", were studied by men such as Percival Lowell, and attributed to irrigation systems built by the Martians to convey water from the snowy polar caps through to the arid equatorial regions.

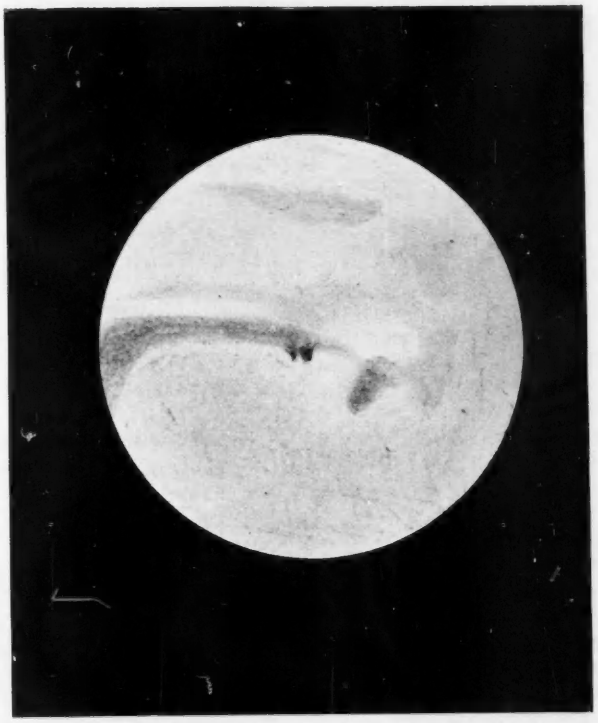


FIG. 2. Drawing of Mars by the author, September 12, 1956, 23 h. 45 m., 12½-in. reflector, ×360.

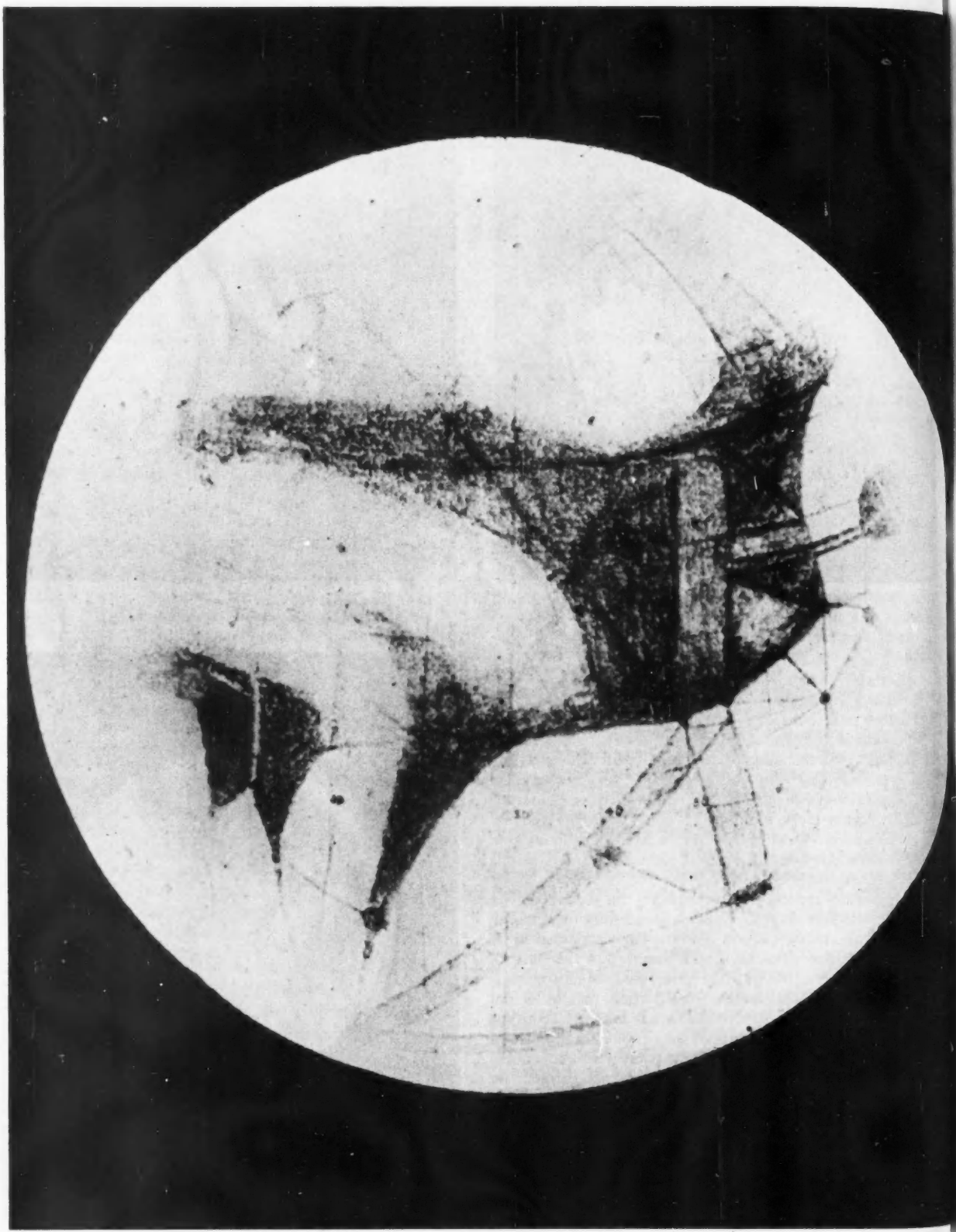


FIG. 3. Drawing of Mars by Lowell. This shows the now rejected "spider network" of canals.

Unfortunately for this idea, we now know that the polar caps are too thin to provide water enough to fill even one major canal—to say nothing of the 800 or so drawn by Lowell. Moreover, it is very doubtful whether the thin, linear canals exist at all. The human eye does tend to join up disconnected spots and streaks into straight lines, and Lowell's artificial-looking network, which reminds one of an intricate spider's-web, has not been confirmed by modern observers using even more powerful equipment. Whatever be the truth of the matter, we may be sure that the canals are not artificial.

Many millions of years ago, Mars may have had much more atmosphere and water than it has now, and there is a chance that higher forms of life flourished there; but few scientists believe that intelligent creatures ever existed. The problem will be solved only when we can actually travel there, and see whether the surface contains fossils of any sort, but on the whole it seems that the intelligent Martians belong only between the pages of a novel.

The atmosphere contains clouds; some of these are probably due to dust-storms, while others are caused by high-altitude ice crystals. Rainfall is certainly unknown on Mars, and the winds are very moderate, judged by terrestrial standards.

It would be wrong to dismiss Mars as being overwhelmingly hostile. Once we have learned enough to travel there, we should also know enough to be able to maintain ourselves, but the thin, unbreathable atmosphere means that living conditions will always be very artificial. It is out of the question to equip Mars with a favourable atmosphere and turn it into a sort of second Earth.

No description of Mars would be complete without reference to the satellites, Phobos and Deimos. Both are dwarf worlds less than a dozen miles in diameter, and both are close to the planet. Phobos revolves at a distance of only 3800 miles above the Martian surface—about as far as from London to Aden—and completes one revolution in only 7½ hours, which means that an observer on the planet would watch it rise in the west and set in the east, crossing the sky in only 4½ hours. For much of this period it would be eclipsed by Mars' shadow, and since it revolves in the plane of the equator it would be unobservable from high latitudes. Deimos is smaller and more distant, so that our hypothetical Martian astronomer would see it only in the guise of a rather large, dim star. Not long ago, a Russian writer suggested that both moonlets might be hollow artificial bodies, built by intelligent beings—presumably to serve as space-stations. This is a fascinating idea, and it is a pity that it cannot be taken seriously. Yet Phobos and Deimos are different in nature from our Moon, and it is quite possible that they are minor planets which were "captured" by Mars in the remote past.

VENUS

Venus, the glorious "evening star" which shines so brilliantly in our skies and seems almost like a small lamp, is a world of very different type. It is only slightly smaller than the Earth, and has a diameter of 7700 miles; its mean distance from the Sun is 67 million miles, and its orbit is practically circular. At its closest it may approach us to within 25 million miles, so that it is then much nearer than Mars. Unfortunately, it is impossible for us to see the actual surface. Venus is hidden by a layer of dense atmosphere which we are quite unable to penetrate, and so far our knowledge is depressingly scanty.

Venus shows regular phases from new to full. When at its closest, at inferior conjunction, it lies more or less between the Earth and the Sun, and its dark side is turned in our direction; when at full phase, Venus is on the far side of the Sun, and its apparent diameter is drastically reduced. Telescopically, the planet is best observed in full daylight. When shining brilliantly in the evening or morning sky, it is bound to be low down, and the combination of glare and poor seeing makes conditions hopelessly unsatisfactory.

The only definite features visible on the disc take the form of vague bright and dusky markings. They are not permanent, but shift and change in an unpredictable manner, and are so nebulous that it is difficult to fix their positions with any accuracy. Often enough the whole planet appears blank. There is no hope of our being able to draw up a map of Venus, as we can of Mars, or even Mercury. All we can see is the upper part of the atmospheric layer.

The rotation period of Venus is still a puzzle. The shadings are not noticeably informative; efforts have been made to watch their drifts across the planet, but the results are discordant and inconclusive. Since 1936 I have made thousands of drawings of Venus in an attempt to derive some kind of a rotation period, but I have had no success whatsoever, and this has also been the experience of many better observers using far better equipment. Photographic and spectroscopic work holds out greater hopes, but although "final and conclusive results" are announced from time to time, we are still very much in the dark. Working at the Pic du Midi, the French astronomer A. Dollfus has recently given a period of 224·7 days; this is the same period as Venus takes to go once round the Sun, in which case one hemisphere would be in permanent sunlight and the other in permanent darkness. Kuiper, in America, prefers a period of about 30 days; radio observations by J. D. Kraus, also in America, indicate a period of only 22¼ hours. At least there is plenty of variety.

Neither do we know the position of Venus' axis. It has been suggested that certain bright areas near the horns of the crescent represent the polar zones, in which case the areas themselves may be due to some peculiarity of atmospheric circulation in these regions; but the whole question is still completely open.

There is no doubt about the existence of an atmosphere round Venus. Yet here again there is no detectable trace of free oxygen; instead, spectroscopic work reveals a tremendous amount of carbon dioxide, and so far as Earth-type creatures are concerned the atmosphere is just as hostile as that of Mars. Admittedly, we can see only the upper layers, but carbon dioxide is a relatively heavy gas, and it is not likely that any free-oxygen zone exists at a lower level.

It is not easy to give any definite height for the atmosphere, but since Venus has a mass very similar to that of the Earth, we may expect a mantle of the same order. Interesting observations are possible on the rare occasions when Venus passes in front of, and occults, a star. On

July 7, 1959, for instance, Venus occulted Regulus, and there was a brief but detectable fading as the star passed behind the planet's atmosphere before disappearing behind the actual disc. Occultations of this kind are very infrequent, and it will be several centuries before Venus again passes in front of a bright star.

In 1956 J. D. Kraus, at Ohio, began to search for radio emission from Venus, using equipment operating at a wavelength of 11 m. By May he was convinced that such emission had been found, and described the signals as having burst-like characteristics not unlike terrestrial atmospherics. Thunderstorms were regarded as a possible cause. So far Kraus's work has not been confirmed, but it does at least represent a new and interesting approach.

This in turn is linked with the so-called Ashen Light, or faint luminosity of the "dark" side of Venus when the planet appears as a crescent. Observations of it go back for centuries, and some of the old theories about it sound strange today; for instance, Gruithuisen, in 1842, suggested that it might be due to vast forest fires on Venus lighted by the local inhabitants to celebrate the crowning of a new ruler. A similar appearance in the case of the Moon is easily explained as caused by light reflected from the Earth, but Venus has no satellite, and the Ashen Light remains very much of a puzzle.

It may be due to pure contrast. On the other hand, there is a good chance that it is caused by electrical phenomena in the planet's atmosphere, perhaps similar to our aurorae, and this idea has been supported recently by spectroscopic work carried out by Nikolai Kozyrev in Russia and G. Newkirk in the United States. Moreover, it seems likely that the magnetic field of Venus is more powerful than that of the Earth, so that there is no reason to doubt that aurorae can occur there. Once again the whole question remains completely open, and we can only hope that we will find out more during the next few years.

Thirty years ago it was commonly believed that Venus must be a world in a condition similar to that of the Earth as it used to be in coal forest times, with abundant moisture, luxuriant vegetation, and primitive amphibian or reptile life. This is an attractive picture, but analysis of the atmosphere has shown that it cannot be the right one, and we must look more closely into the matter.

Two theories hold the field at present. Venus may be a dust-desert, without a scrap of moisture, and with violent winds blowing through the dense, unbreathable atmosphere; we can at least be sure that the surface temperature is high, since carbon dioxide has a powerful "greenhouse" effect. On the other hand, two American astronomers, F. L. Whipple and Donald H. Menzel, have suggested that the clouds may be composed of H_2O, and that the surface of the planet is completely covered with water.

If we agree with the second view, we cannot rule out the possibility of simple marine creatures. Life on Earth began in the sea, in Pre-Cambrian times, and at that period our atmosphere contained more carbon dioxide and less water vapour than it does now. There is a chance that life is just beginning on Venus, in which case it may eventually develop. Yet all this is pure speculation, and we have almost no concrete information to guide us. Present-day theories about the nature of the surface may prove to be wildly wrong.

THE LANDSCAPE OF MERCURY

Mercury, the other member of the group of inner planets, has a diameter of just over 3000 miles. It is thus not a great deal larger than the Moon; and since its mean distance from the Sun is only 36 million miles, it is not easy to study. Small telescopes show nothing but the characteristic phase, and even surface maps drawn with the aid of large instruments are of dubious accuracy. The chart drawn over

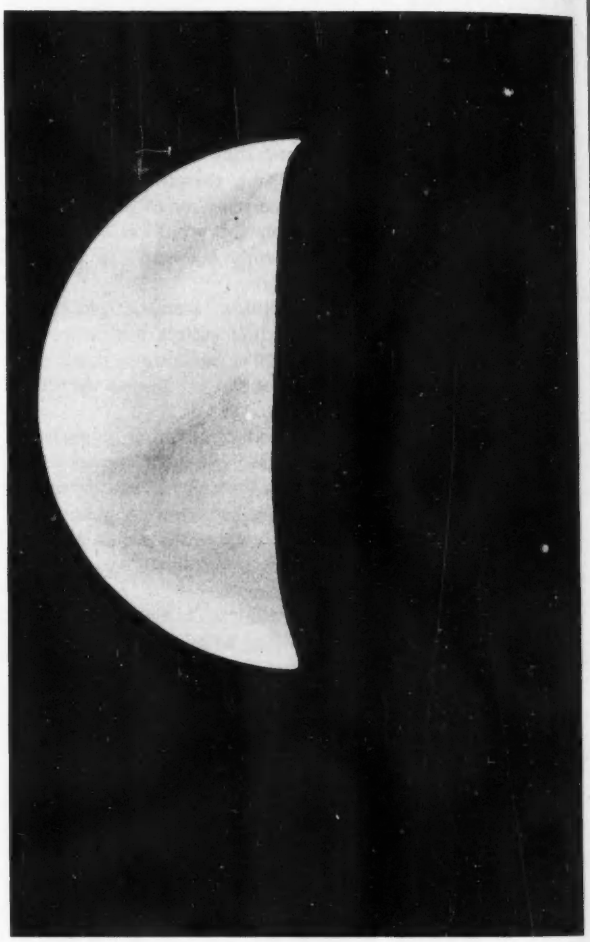


FIG. 4. Venus, drawn by the author; 12½-in. reflector, ×360. The drawing was made at 14 h. 19 m. on July 7, 1959, just before the occultation of Regulus; Regulus itself is shown.

a quarter of a century ago by E. M. Antoniadi, using the 33-in. refractor at the Observatory of Meudon, remains the best. Darkish areas can be made out, and the positions of some of them, such as the Solitudo Hermae Trismegisti, may be defined with some degree of certainty, but we can glimpse only the coarse details.

Mercury takes 88 days to complete one revolution round the Sun. This is also the period of the axial rotation, so that part of Mercury has permanent "day" while another part has permanent "night". In the hottest part of the day-zone the temperature must exceed 700°F, while the region where the Sun never rises must be intensely cold—far colder, indeed, than any part of the Earth or Mars. Between

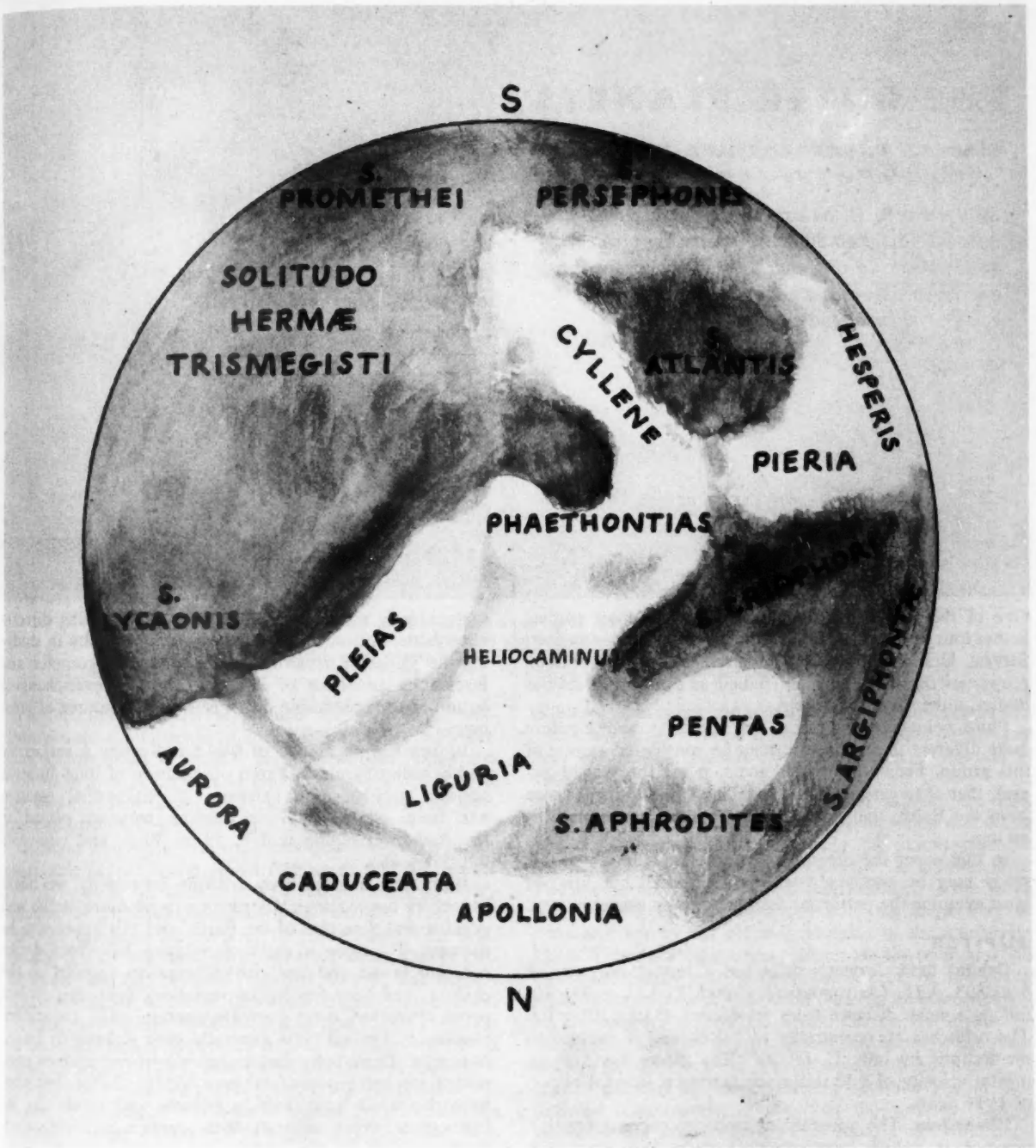


FIG. 5. Nomenclature of the surface features of Mercury, based on the chart by E. M. Antoniadi.

these two zones there is a region over which the Sun would appear to rise and set, and where the temperatures would be less extreme, but it is obvious that Mercury is a world quite unsuited to life in any form. Dollfus has detected a very thin atmosphere, but the ground density cannot be more than 1/300 of that of the Earth's air at sea-level.

Mountains may exist on Mercury, and it is even possible that there are craters similar to those of the Moon, but our present telescopes are inadequate to tell us more. It would be difficult to visualise a more hostile world.

It is true that we cannot hope to find intelligent life on Mars, Venus, or Mercury, but all three are fascinating worlds, and each has its own particular points of interest. Intensive studies are now being carried on, and each year sees us probing more deeply into the problems associated with our companions in the Solar System.

THE OUTER PLANETS

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Several models of the structure of the outer planets have been proposed but there remains the problem of confirmation. To this end, present-day observations are directed towards a better understanding of their physical and chemical properties.

One of the most important features of the outer planets is that four of them, the so-called "major" planets—Jupiter, Saturn, Uranus, and Neptune—have so many common properties that they may be studied as a group of similar bodies, rather than separately.

Pluto, being very inferior in size and mass, and therefore quite different in structure, cannot be considered as part of this group. From the details given, it will be seen, however, that observation of it is so difficult, due to its distance from the Earth, that its omission from the group study is no loss.

In this paper the present and future ways in which this study may be conducted will be discussed, but first we must examine the particular features of each planet in turn.

JUPITER

Orbital data. Jupiter's orbit has a semi-major axis of 5·202803 A.U. (Astronomical Units: 1 A.U. $\simeq 93\times10^6$ miles), a mean distance from the Sun of $483{\cdot}3\times10^6$ miles. The orbit has an eccentricity of 0·0484 and is inclined to the Ecliptic by only 1° 18′ 20″. The planet has a mean orbital velocity of 8·12 miles/sec., giving a sidereal period of 11·86 years.

Dimensions. The apparent diameter at mean opposition distance is 46″·86, corresponding to a true equatorial diameter of 88,700 miles. As Jupiter is an oblate spheroid the polar diameter is only some 0·93 of this figure.

The mass of Jupiter is 318·4 times that of the Earth, but its density is only 1·34 times that of water, less than 0·25 the density of the Earth.

The axis of rotation is inclined by 3° 4′ to the perpendicular to the orbital plane.

Physical data. None of the planets presents the observer with such a wealth of detail as do Mars and Jupiter; unlike the former, however, Jupiter does not display an actual surface, only the outermost, gaseous layers being directly observable. Although this creates much difficulty in studying the planet, it nevertheless presents many complex and fascinating problems of its own, and the ever-changing nature of the observable detail is in itself a source of great interest.

Jupiter has an albedo of 0·44,* indicating a surface of highly reflecting cloud. From observation of long-duration surface markings the existence of differential rotation has been established; the average rotation period in the equatorial region is 9 h. 50 m. 30 s., and elsewhere 9 h. 55 m. 41 s.

With such a large body rotating so rapidly we might expect its meteorological structure to be more stable and symmetrical than that of the Earth, and this appears to be the case. The gases in the surface layers have been drawn out into broad and well-defined currents parallel to the equator, and very few major variations from this pattern occur. Parts of these currents contain dark coloration, forming latitudinal belts generally grey to reddish brown in colour. These belts vary in intensity from year to year, sometimes being almost or even totally absent, but they have displayed little drift in latitude and rarely do the light zones which separate them contain any very dark matter.

The Jovian "atmosphere" appears to be subject to violent activity. Its "storms" are of a slower and longer enduring type than the terrestrial variety, since the dense gases under great gravitational compression must have a very high viscosity. Despite this the activity is sometimes on a grand scale; belts have changed their entire structure in as little as two or three days, others scarcely observable for some time suddenly break out again very dark and wide, and

* The albedo of a body is the fraction of the total incident sunlight which it reflects in all directions.

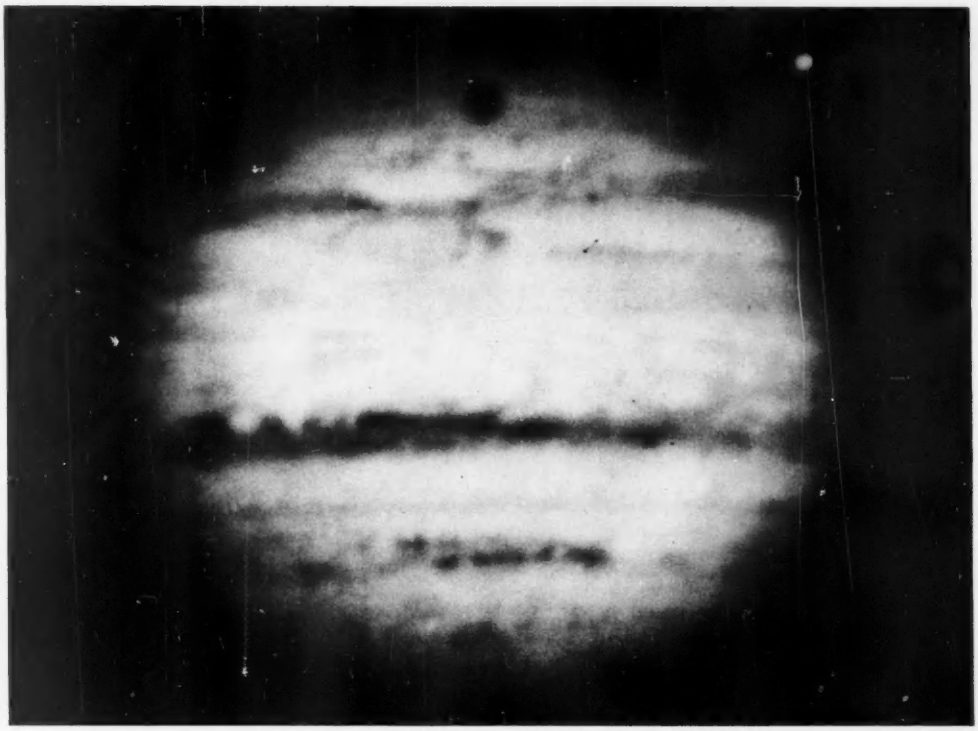

FIG. 1. Jupiter, photographed with the 200-in. telescope; (*a*) in blue light, (*b*) in red light. Notice one of the satellites and its shadow, and the darkness of the red spot in the blue light photograph. Changed positions are due to rotation of the planet between exposures.

(By courtesy of the Mount Wilson and Palomar Observatories)

sometimes doubled, and often in a very broken up and disturbed state. Outbreaks of dark spots occur—often these spots appear one after another at the same point, and move away with a rapid motion in longitude. Minor changes in belt structure and colour, and less turbulent dark and light spots and streaks are constantly being observed.

So many and varied are the phenomena occurring in the observable layers of the planet that space will not permit even a mention of them here. One cannot omit, however, mention of Jupiter's best-known feature, the great Red Spot. In the southern edge of the south equatorial belt, usually one of the most prominent markings, there is an enormous bay or "hollow". In this hollow, and almost filling the great width of the south tropical zone, is an elliptical spot, some 30,000 miles long and 12,000 to 15,000 miles wide, which sometimes appears a deep red (as in 1878–82, 1920, 1926–7, and 1936–7), and often fades to a pale pink or neutral grey, and occasionally disappears completely. This feature has been identified with certainty on drawings dating back to 1831, and probably to 1664; it is difficult to regard a feature of such permanence as a transient meteorological phenomenon, and early workers considered it to mark some mountain mass or even a volcano on the solid surface. This idea is obviously untenable in the light of our present-day knowledge of the nature and density of the so-called "atmosphere"; also the Red Spot displays a motion far removed from the necessarily uniform rotation of a solid core. A theory widely held for some years was that the Red Spot was a solid body floating in the dense atmosphere; one of the high-pressure ices was suggested for its composition, but modern estimates of the mean molecular weight at the observable "surface" do not support this. More recent suggestions have included a pressure-crystallised form of helium, or metallic ammonia.

In the case of both the Red Spot and many of the other surface phenomena it is the feeling of the writer and others that we are actually observing only the manifestation at the visible surface of some phenomenon at a lower level. The source may well have uniform rotation, as the variations in the motions of the visible markings may be accounted for by the differing motions in the intervening levels. The observed spot may thus mark the point at which either the matter ejected from the source, or the visible effect of some physical condition (such as pressure, density, or temperature anomalies) break the visible surface. A mechanism such as this would explain many of the peculiarities of the observed phenomena. If it is, in fact, the correct mechanism, the feature as observed should have suffered considerable diffusion on the way up, and its apparent size might then give us some clue to the depth of the source. Examination of pairs of photographs made in long- and short-wave light discloses a much finer structural detail in the more penetrating long-wave radiation; interpreted as a diffusion effect this tends to support the hypothesis (see Fig. 1).

It is important to search for any relationship between observed phenomena, many of which appear to recur at varying intervals. At present very few simple correlations have been definitely established, but as the data accumulates it seems that some possible relationships are appearing.

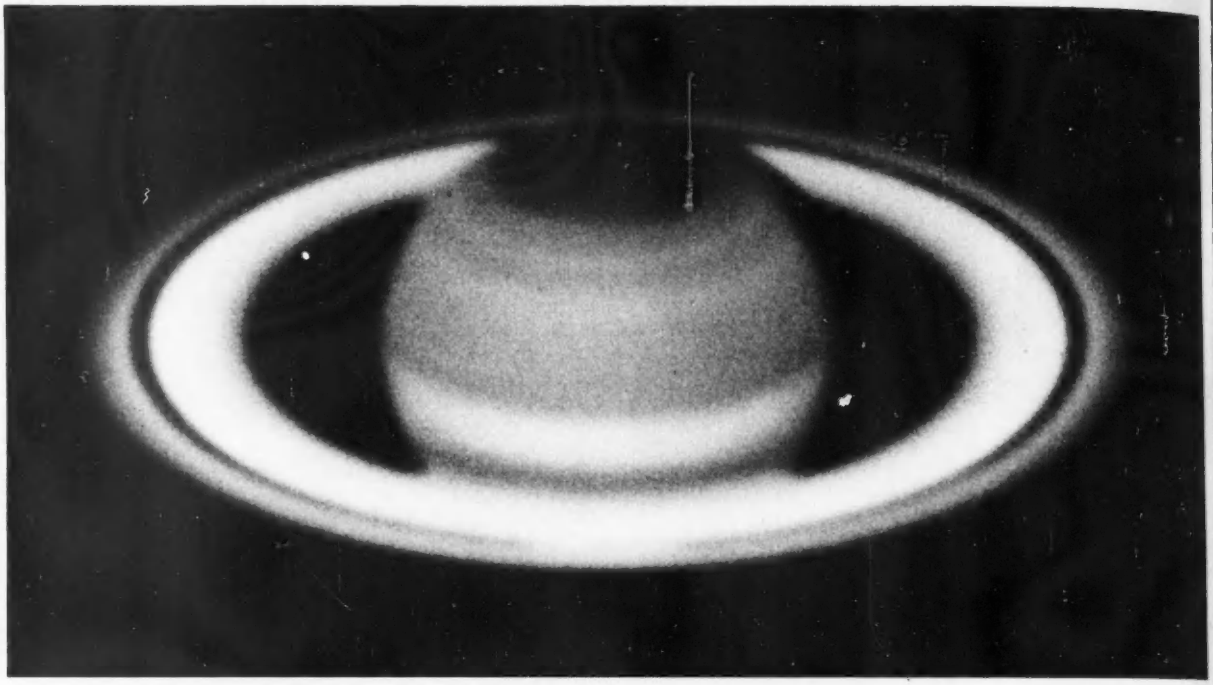

FIG. 2. Saturn, photographed with the 100-in. telescope.

SATURN

Orbital data. The semi-major axis is 9·538843 A.U., a mean distance from the Sun of $886{\cdot}1 \times 10^6$ miles. The eccentricity is 0·0557, rather greater than that of Jupiter. The orbit is inclined to the Ecliptic by 2° 29′ 24″. The sidereal period is 29·46 years, the planet having a mean orbital velocity of 6·0 miles/sec.

Dimensions and physical data. The apparent diameter at mean opposition distance is 19″·52, an actual equatorial diameter of 75,100 miles; due to the oblateness the polar diameter is 0·89 of this.

The mass is 95·2 times that of the Earth, corresponding to a density of only 0·69 (water=1), just 0·12 the density of the Earth. Saturn is thus by far the least dense of the planets.

Having a similar gaseous mantle to that of Jupiter, Saturn's albedo is almost the same, 0·42. The telescopic appearance is also like Jupiter's, although owing to the greater distance fine detail is very much more difficult to detect. From observation of a white equatorial spot discovered by Asaph Hall at Washington in 1876, the period of axial rotation appeared to be 10 h. 15 m. Such spots are rare, but the rotation period was finally shown to be 10 h. 14 m. by observations (spread over more than a month) of a large, white, oval spot in the equatorial zone which was discovered on August 3, 1933, by the late Will Hay—a very capable amateur astronomer, although better known to the general public as a leader in the entertainment world. This figure has since been confirmed by spectroscopic observations. Observation of occasional spots in higher latitudes suggest differential rotation of the gaseous surface similar to that of Jupiter; for instance, a spot which appeared in latitude 35° N in 1903 had a rotation period of 10 h. 38 m.

The ring system. When favourably placed and observed with a moderate or large telescope, Saturn is one of the most striking and beautiful objects man is privileged to witness. No doubt one of the principal reasons for this is the unique system of rings which encircle its globe (Fig. 2). There are three quite separate rings, known as ring A (the outermost), ring B (the middle one, whose outer portion is usually more brilliant than the brightest part of the globe), and ring C (the innermost, also known as the Crêpe ring from its faint, misty appearance). The gap between rings A and B was first recorded by Jean-Dominique Cassini in 1675, and is named after him.

The dimensions of the system are: ring A, 10,150 miles wide; Cassini's Division, 1750 miles; ring B, 16,450 miles; ring C, 9850 miles; gap between ring C and surface of globe, 8900 miles. The total diameter of the system is thus 169,300 miles, more than twice that of the globe alone and almost twice that of Jupiter.

The remarkable feature of the ring system is its thinness—shown by modern measurements to be less than 10 miles. Small wonder that when the Earth passes through the equatorial plane of Saturn and the rings are "edge-on" to us, they cannot be seen. It can be shown to be impossible for a solid structure to be so thin relative to its surface area, and speculation as to the nature of the rings was rife for many years. Modern spectroscopic evidence shows that they must in fact consist of thousands of tiny bodies in individual orbits round the planet. This had been suspected earlier, following observations of stars *through* the rings. It has been suggested that these particles are the remains of a satellite disrupted by the tidal forces set up by too close an approach to the parent planet.

URANUS

This, the first discovered planet, was spotted by Sir William Herschel on March 13, 1781, whilst he was examining stars in the constellation Gemini with a reflecting telescope of 6·2-in. aperture. It is interesting to note that the object had been recorded nineteen times during the previous ninety years, but its planetary nature had not been recognised.

Orbital data. The semi-major axis is 19·181979 A.U., or 1783×10^6 miles; the discovery of Uranus thus doubled the size of the known Solar System. The eccentricity of the orbit is 0·0472, and it is inclined to the Ecliptic by only 0° 46′ 23″. The sidereal period is 84·01 years. The planet has thus completed only a little more than two revolutions since its discovery. The mean orbital velocity is 4·22 miles/sec.

Dimensions. The apparent diameter at mean opposition distance being 3″·58, the diameter is about 29,300 miles. The measurement of the discs of the outer planets is extremely difficult, requiring the best of telescopic equipment and great precision. The figures given here are based on a recent investigation by G. P. Kuiper, Director of the Yerkes and McDonald Observatories in the U.S.A. The mass of Uranus is 14·6 that of the Earth.

Uranus is unique in the Solar System, in that its axis of rotation is inclined to the perpendicular to the plane of its orbit by more than a right angle. Identifying the "North" pole by the direction of rotation, the inclination is found to be 97° 53′. It is important to note that the five satellites of Uranus revolve in its equatorial plane and revolve in the direction of its rotation—both being spuriously "retrograde" due to the high inclination.

Physical data. Uranus has a density of 1·60 that of water, less than 0·33 that of the Earth. Its albedo is 0·45, similar to the other major planets. Owing to the small angular diameter observation of the surface is difficult and the province of powerful telescopes only. In general, the appearance is very similar to that of Jupiter and Saturn, most observers agreeing on the existence of a bright equatorial zone bounded by dusky belts. The colour of the disc is usually a pale greenish blue. Spots or other condensations in the belts are rarely seen, but those that have been observed show the rotation period to be about 10 h. 44 m. (See Fig. 3.)

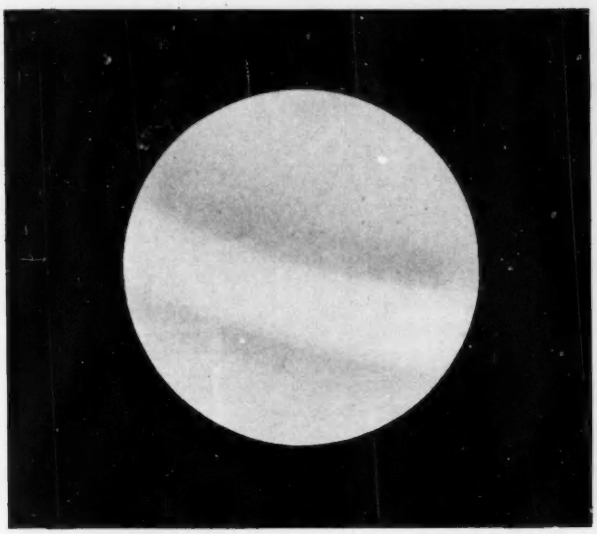

FIG. 3. Uranus, drawn by W. H. Steavenson, 1915.

NEPTUNE

During the half-century following the discovery of Uranus many attempts were made to compute an accurate orbit, but it steadfastly refused to obey predictions of its motion based upon any of them. Eventually the suggestion was made that perhaps the irregularities were due to the perturbing effect of an undiscovered trans-Uranian planet. Among those who took up the problem of trying to calculate the dimensions and position of such a planet, two were pre-eminent: John Couch Adams, a Cambridge graduate; and Urbain Le Verrier, a leading French mathematician. Adams was the first to derive a solution, his preliminary figures being completed by the end of 1843. Unfortunately, through a series of misunderstandings involving Adams, G. B. Airy (the Astronomer Royal) and others, a search was not made for the new body at this time. Le Verrier's solution was published in June 1846, and gave the position of the planet within a degree of that indicated by Adams's work. A search, using Adams's figures, was immediately commenced at Cambridge, but it was too late. At Berlin Observatory, J. Galle and H. D'Arrest, who had received a copy of Le Verrier's paper, also commenced a search, and they were aided by the possession of a new chart of the part of the sky concerned which had not then been published and so was not available to the English observers. The Berlin workers were thus able to confirm and announce discovery of the object some days ahead of the Cambridge observers. There was considerable controversy at the time as to which mathematician deserved credit for the prediction, Adams or Le Verrier; in these more enlightened times full credit is usually given to both for their tremendous and independent work.

Orbital data. The semi-major axis is 30·057695 A.U., representing a mean distance from the Sun of 2793×10^6 miles. The eccentricity is 0·0086, the lowest for the major planets. Inclination to the Ecliptic is 1° 46′ 26″. The sidereal period is 164·79 years, the mean orbital velocity being 3·37 miles/sec.

Dimensions. An even poorer telescopic object than Uranus, the apparent diameter of the disc is difficult to measure but appears to be a little over 2 sec. of arc. The most recent determination, by H. Camichel of the Pic-du-Midi observatory in the French Pyrénées, gives 2″·12—making the diameter 27,700 miles. Neptune's mass is 17·3 times that of the Earth, the density being 2·23 that of water. The axis of rotation is inclined 28° 48′ to the perpendicular to the orbital plane.

Physical data. It will be seen from the figure quoted in the preceding paragraph that Neptune is the densest of the major planets. Its albedo is about 0·50. The general appearance with large telescopes is a tiny, bluish-white disc; observations made in recent years with some of the world's giant instruments show a bright equatorial zone bordered by dusky belts, very similar to Uranus. The axial rotation period is about 15 hours, but determinations of this have been very uncertain owing to the rarity of reasonably permanent, discrete markings.

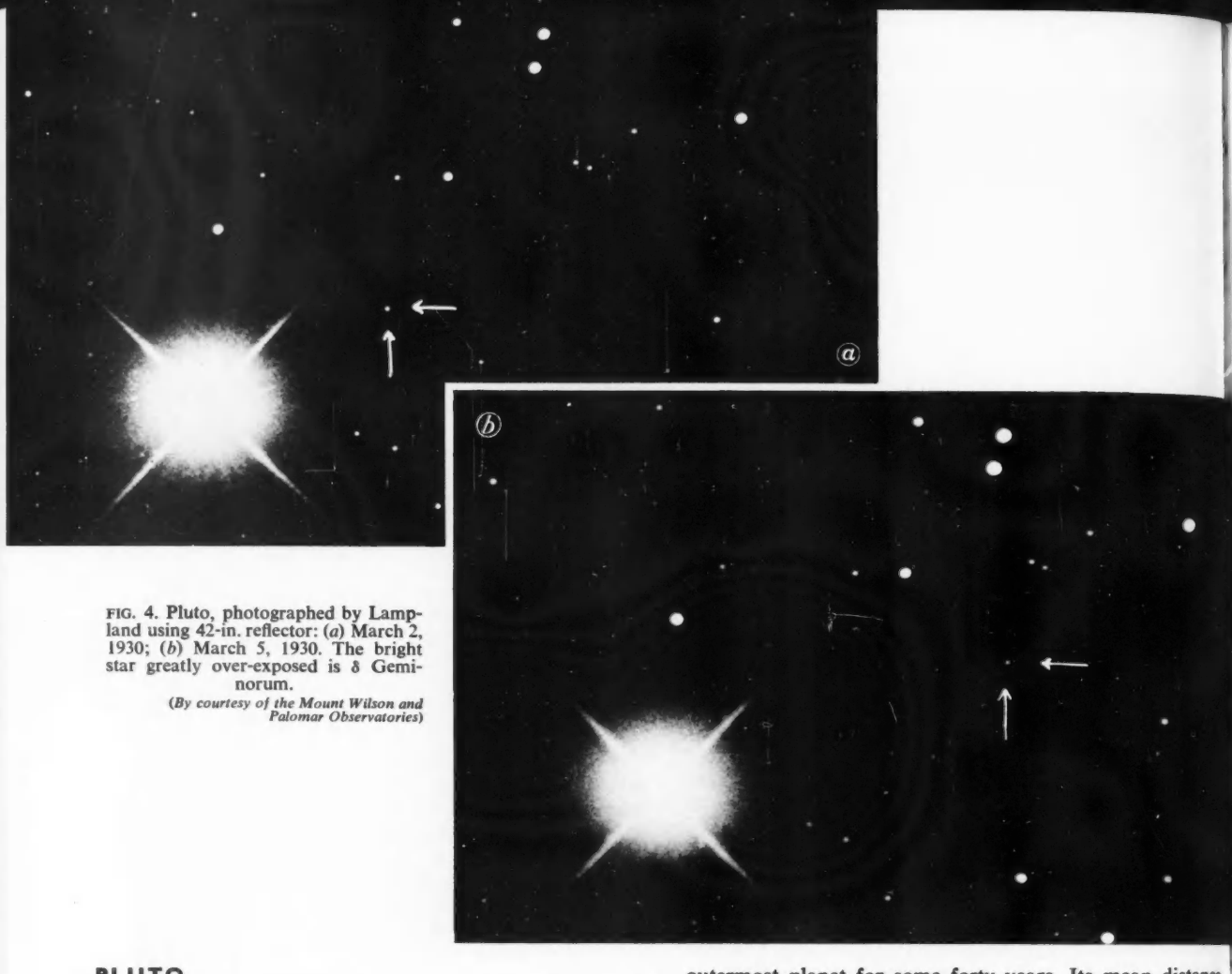

FIG. 4. Pluto, photographed by Lampland using 42-in. reflector: (*a*) March 2, 1930; (*b*) March 5, 1930. The bright star greatly over-exposed is δ Geminorum.

(By courtesy of the Mount Wilson and Palomar Observatories)

PLUTO

It gradually became apparent during the years following the discovery of Neptune that the new planet did not account fully for the discrepancies in the motion of Uranus, and eventually the possibility of there being a further, trans-Neptunian planet had to be considered. Foremost among the mathematical astronomers who undertook this study were Percival Lowell, perhaps better remembered for his (partly less reputable) work on Mars, and W. H. Pickering. Both produced a position for the missing planet, and there was a remarkable agreement between them, although they had used quite different methods. A search was immediately undertaken at the Mount Wilson Observatory, but the hypothetical planet was not found. More than a decade passed, until in 1929 the staff of Lowell's own observatory at Flagstaff, Arizona, decided to search once more for the planet their late Director had striven so hard to locate. A new 13-in. photographic refractor was used, and the planet was discovered by Clyde Tombaugh on a plate taken early in 1930. Its planetary nature was confirmed by a pair of oft-reproduced and now famous photographs, taken in March of the same year (Fig. 4).

Orbital data. Pluto's eccentricity, 0·2486, is the highest among the nine planetary orbits. As a result of this the orbit lies partly inside that of Neptune, and in fact in 1969 Pluto will cross the orbit of Neptune and cease to be the outermost planet for some forty years. Its mean distance from the Sun is far greater than Neptune's, however, being 3666×10^6 miles. The orbit is inclined to the Ecliptic by more than 17° (Neptune less than 2°), so there is no possibility of a collision between the two bodies. Pluto has a mean orbital velocity of 2·94 miles/sec., only 1/10 that of the innermost planet, Mercury.

Dimensions. The disc of Pluto is only measurable, with difficulty, with the aid of the largest telescopes in existence. It is still somewhat uncertain, but recent work by Kuiper and Camichel shows the diameter to be about 4900 miles, a little larger than was previously thought. The density is about four times that of water, and the mass only 1/10 that of the Earth. These results are very surprising, as a body of these dimensions will have far too slight a gravitational attraction to account for the observed perturbations of Uranus and Neptune, *upon which the calculations leading to its discovery were based*. This paradox raises several questions; for instance, was the agreement between the various computers, and the subsequent discovery of the planet in the predicted position, one colossal coincidence? Are there other bodies still to be discovered? If so, it is unlikely that they could have remained undetected until now, unless they are so small as to play no very significant part in the problem: so at present the perturbations of the outer planets are still not completely explained.

PRESENT AND FUTURE WORK

The physical constitution of the outer planets is very different from that of the terrestrial planets; R. Wildt, in 1930, following up the earlier work of Sir Harold Jeffreys, deduced a model for Jupiter based upon a careful analysis of the known mass, volume, mean density, and the fundamental laws of physics, which suggested that the planet consisted of a solid core (probably of metallic rocks) only some 18,500 miles in radius, surrounded first by an "ocean" of frozen gases 17,000 miles deep and above that a gaseous mantle 8000 miles deep. This model was widely accepted for many years, but it presents many problems to the cosmogonist; all tenable theories presuppose that the planets were formed from solar or quasi-solar material, which implies a high percentage of hydrogen. The lack of such high quantities of hydrogen can be explained in the case of the inner planets by their low gravitational pull, but one would expect the more massive major planets to have retained a large proportion of it. A reassessment of the problem by W. H. Ramsey has shown that Wildt's assumed mean densities for core and ice-layer were too low; he suggests that the deduced amounts of the heavier elements are far too large, and that the increase in density towards the centre of the major planets may be due not to chemically heterogeneous layers formed by gravitational separation during formation but to phase changes in a completely homogeneous planet. Recent laboratory research has demonstrated that under extreme pressure many normally non-metallic elements suffer a change in their molecular structure and become dense and metallic. It should be noted in support of Ramsey's theory that the pressure at the centre of Jupiter is about forty times the critical pressure for the existence of metallic hydrogen. Ramsey thus estimates the actual hydrogen content of the planet as between 76% and 84% by mass.

Both workers extended their calculations to Saturn, Uranus, and Neptune. The figures differ to some extent from planet to planet, but the arguments are the same. It seems that in the light of present knowledge Ramsey's model is the more likely, but the problem now rests with the observer, who must endeavour to gather sufficient evidence to prove or disprove these and any further theories that may be put forward. Observations of the outer planets is therefore largely directed towards a better understanding of their physical and chemical properties; some of the principal ways in which this can be tackled can be summarised in the following paragraphs.

Visual observation. Measurement of the positions and day-to-day motions of the surface features; estimates of relative intensities of surface markings and observations with colour-filters. (The latter are subject to considerable errors—instrumental, atmospheric, and personal—and thus are frequently of doubtful value.)

Photographic observation. Until comparatively recently photographs of the outer planets were of limited value, owing to their small apparent sizes and to the "blurring" effect of disturbances in the Earth's atmosphere during the long exposures required. Even now, superlative techniques and equipment are necessary to record sufficiently fine detail for the photograph to have more than an aesthetic value. Probably the most useful photographs are those made in rapid succession in two or more different wavelengths. Series of exposures throughout the spectrum are very informative, but even pairs of exposures—for example, in infra-red or red and in ultra-violet or blue light—are valuable; owing to the greater penetration of the longer wavelength radiation, they permit near-simultaneous observation of the state of the outermost surface and of a lower level in the gaseous mantle of the planet (see Fig. 1).

Spectrographic observation. This, is, of course, the most obvious line of attack on the problem of the constitution of the outer planets; its use is, however, limited to their outermost layers, at which reflection of the Sun's light takes place. As we have seen, the proportions of the various substances observed here are unlikely to hold for levels deeper in the planet's interior.

Fig. 5 shows the spectra of the four major planets; the spectrum of the Moon is also shown as a comparison, so that the lines attributable to the reflected sunlight may be identified. An absorption band due to the ammonia radical, NH_3, can be plainly seen in the Jupiter spectrum; it is only barely visible in that of Saturn, and missing from those of Uranus and Neptune. This reduction in the amount of ammonia observed in the more distant, and therefore colder, planets is no doubt due to its having condensed out of the observable layers. Numerous bands due to methane, CH_4, appear in the spectra of all four planets, and strengthen with distance from the Sun. No other components have been detected with certainty, but from a consideration of the known facts and the physical conditions which obtain, it is possible to postulate the presence of very large quantities of hydrogen (see above), large amounts of helium, and small amounts of argon and other rare gases. Oxygen and nitrogen in the free state, and oxides of carbon and the higher hydrocarbons, are unlikely to be present.

Radio observation. In 1955 Jupiter was discovered to be a source of radio noise; its emissions are intermittent and at a rather low frequency, but are often intense. This major discovery has led to close co-operation between radio and visual observers, and already some interesting results have emerged. The radio sources have been shown to be localised in small areas of the planet's surface, and derived rotation periods suggest that they lie in non-equatorial regions of the disc. Reception of noise has coincided, in many cases, with the central-meridian passage of the great Red Spot, and of three large, oval, white spots which have been permanent features of the disc for the past eighteen years, and to have increased fourfold when one of these white spots was in conjunction with the Red Spot. This is strong but not yet conclusive evidence in support of these visible spots being directly connected with the radio sources. The radio emission also may originate at sub-surface levels, but may be expected to travel outwards through the higher layers without deviation; radio-determined longitudes of a particular source should therefore be its true longitude. The difference, and variations in the difference, between this and the longitude of a visually observed associated spot could thus yield much information about the sub-surface currents.

It is possible that the next decade will see the development of collateral radio/visual observing techniques that will permit great advances in our study of these planets. The discussion of the many possibilities such techniques

FIG. 5. Spectra of Jupiter, Saturn, Uranus, and Neptune. Spectrum of the Moon is given to identify those lines which are common to all four and due to the reflected sunlight. Notice the absorption bands of ammonia (NH_3) in Jupiter and Saturn and of methane (CH_4) in all four.

would offer would be too lengthy to include here; it would require a great deal of expensive administration and equipment to get such a project under way, but the results obtained would be well worth it.

Positional and dynamical astronomy. This is almost invariably the work of the great national observatories, as it requires special equipment not often found elsewhere, and a great deal has been achieved in the field. In the case of the outer planets, however, there is still room for improvement in our knowledge of their dimensions and orbital elements. This work is likely to continue for a considerable number of years, at least.

Observations of the satellite systems, especially those of Jupiter, Saturn, and Uranus, are of great value. The great Dutch astronomer Willem de Sitter pointed out in 1931 that a study of the motions of the four largest satellites of Jupiter for a little over three centuries was equivalent to nearly 18,000 years' observation of the four inner planets as a system, or to over 1,100,000 years' observation of the outer planets. There is thus much value in studying these satellite systems, considering them as small-scale models of the Solar System.

Colour microphotometry. A new and potentially valuable technique has recently been devised by M. G. Gadsden, using photographs of Jupiter made on a standard reversal-type colour film. The photographs were separately scanned in a recording microphotometer through red, green, and blue filters; thus from the microphotometer traces any variation in the intensity of a particular feature with wavelength can be determined, and in addition latitudes of features can be obtained which are in excellent agreement with those observed visually using a micrometer.

Extra-terrestrial observation. Current developments in space technology suggest that within a few decades it may be possible to set up elaborate observing equipment on some form of artificial satellite body, and thus make observations from outside the Earth's atmosphere. Most of the types of observation detailed in the preceding paragraphs would benefit from this; the improvement in photographic and spectrographic results might be considerable. It seems extremely unlikely that sufficient stability could ever be achieved to permit metrical observation from such a platform.

We may also look forward to improving our knowledge of the outer planets by literally "having a closer look"—by the use of so-called "artificial planets" to carry observational equipment much closer to them. Not all desirable results can be put into a form suitable for return to Earth by telemetry, however, and the retrieval of the information obtained would be a big problem. It is conceivable that radar and television techniques could assist in the partial overcoming of this difficulty, but actual retrieval of instruments from the vehicle would be much more profitable. The retrieval of instruments even from such local vehicles as high-altitude rockets is proving difficult; one imagines it will be much more so from hundreds or e en thousands of millions of miles. Despite Prof. Hoyle's view, it appears there would be much that a man could do to supplement the instruments in such a vehicle, and the retrieval of a man would not seem to be a much greater difficulty than retrieval of an instrument container.

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COMETS, METEORS, AND MINOR PLANETS

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Before the first manned vehicle is sent into space, we need to know much more about hazards from impact with interplanetary material. Observations from Earth have given us little more than orbital data on Comets, Meteors, and Minor Planets; the crucial information will come from rocket research.

COMETS

A typical comet appears as a hazy patch in the sky. It is proved to be a comet rather than a nebula by its movement, in an hour or so, against the background of stars. If it is a bright comet it will have a tail which points more or less away from the Sun. For convenience when observing, a comet is divided into parts with the following descriptive names: the *nucleus*, which can be seen only with large telescopes, when it appears as a stellar point; the *coma*, which surrounds the nucleus and diffuses outwards from it; the *tail*, which may have a great variety of forms—straight, curved, fan-shaped, and so on. As comets are brightest when near the Sun, they are commonly seen in the western sky in the evening and in the east before sunrise.

When a comet is discovered, notification of the event is sent to the Bureau of the International Astronomical Union at Copenhagen. There it receives a provisional designation consisting of the year and a letter to indicate the order of discovery in that year. The comet is named after the discoverer. Later, the comet receives a final designation consisting of the year in which it passes through perihelion (the closest point to the Sun) and a Roman numeral to indicate the order of perihelion passage in that year. This is done two or three years in arrear, so that a later discovery will not upset the order.

Comets are discovered in two ways. Sometimes their images are recorded on plates exposed by professional astronomers for other purposes. Otherwise they are found by deliberate visual searching—usually by amateur astronomers. Comet Arend-Roland, 1956h, was discovered photographically by these two professional astronomers at Uccle when it was about magnitude 10. Orbit calculations, made shortly after its discovery, showed that the comet was likely to be a brilliant object of zero magnitude in the spring of 1957. Expectations were more than fulfilled, the comet was not only bright, it also showed a "beard" and a "spike". These rare features were composed of cometary material spread in the plane of the comet's orbit and would have remained invisible if the Earth had not been presented with an edge view as it passed through the plane.

A good example of success in deliberate "comet sweeping" occurred recently when G. E. D. Alcock found two new comets within five days, on August 25 and 29, 1959. He "sweeps" the sky regularly with a 105 mm.×25 binocular telescope, and when he finds a comet-like object he first checks from a star chart that it is not a nebula. Then he notes its position and watches to see if it moves, to prove it is a comet. These two discoveries are a just tribute to his perseverance, for he had been looking for over six years to a total of about 650 hours when he discovered his first comet.

Periodic Comets. Halley was the first person to discover that a comet may move in a periodic orbit: an ellipse with the Sun at one focus. Up to the present time, over forty comets with small elliptic orbits having relatively short periods are known, and have been observed at more than one return to perihelion. About an equal number have been seen at one apparition only. A typical short-period comet moves in the same direction as the major planets, in an orbit not much inclined to theirs, with a period of six or seven years.

Most of the known short-period comets move near Jupiter's orbit at aphelion (farthest point from the Sun), and are near the Earth's orbit at perihelion. Only those comets that are favourably placed or move near the Earth have been discovered, and there must be a large number still awaiting discovery.

The influence of Jupiter on the orbits of most of the periodic comets is so overwhelming that they are often referred to as "Jupiter's family". It is generally assumed that these comets were originally moving in near-parabolic orbits and were "captured" by a very close approach to Jupiter.

Predictions for the successive returns of nearly all of the periodic comets are calculated by the Computing Section of the British Astronomical Association. The predicted perihelion times are commonly good to one day and are often even better than this.

Near-parabolic Orbits. About 85% of all known comet orbits are, to a good first approximation, parabolas. As it simplifies the working, preliminary calculations usually assume a strictly parabolic orbit. Unless the comet turns out to be a periodic one, this orbit will be good enough to allow the comet to be followed and observed.

When the comet has become too faint to be observed any more, all the observations are collected together and used to calculate a definitive orbit. This will show whether the orbit is really an ellipse, a parabola, or a hyperbola. The existence of hyperbolic orbits suggests that comets come from outside the Solar System, but when account is taken of perturbations by the planets, backwards in time, no orbit is found to remain significantly hyperbolic. Thus all the comets, for which orbits have been calculated, are members of the Solar System.

A great many theories have been advanced to account for the origin of comets, but there just is not enough observational material available to reach any final conclusions on the matter.

Composition. When it comes to what a comet is made of, however, we are on safer ground. Spectral analysis shows the presence of such simple molecules as CH_4, C_2N_2, CO_2, NH_3, and H_2O. Also, meteors are known to have a close association with comets. Prof. Whipple of Harvard, who has increased our knowledge of meteors considerably,

FIG. 1. Comet Arend-Roland, photographed on April 24, 1957, by R. L. Waterfield at his private observatory at Ascot.

has combined these two facts into what he calls his "Ice-model" hypothesis. This attractive theory suggests that a comet nucleus is made from a mixture of meteoric and ice particles, the "ices" being the simple gases already mentioned, solidified at the low temperatures prevalent in interplanetary space. As the comet passes close to the Sun, solar radiation causes some of the gases to vaporise to form the coma and the tail. Some unpredictable phenomena associated with comets—outbursts, jets, and so on—are easily accounted for by irregular vaporisation. Eventually, when all the gases have disappeared, the meteoric dust will be dispersed to form a meteor stream.

An orbital difficulty can also be explained by this hypothesis, by assuming that the comet nucleus is rotating while vaporisation takes place. This will cause either an acceleration or deceleration in the motion of the comet, according to the direction of rotation. Such effects are noted in a few well-observed periodic comets and are difficult to explain in any other way.

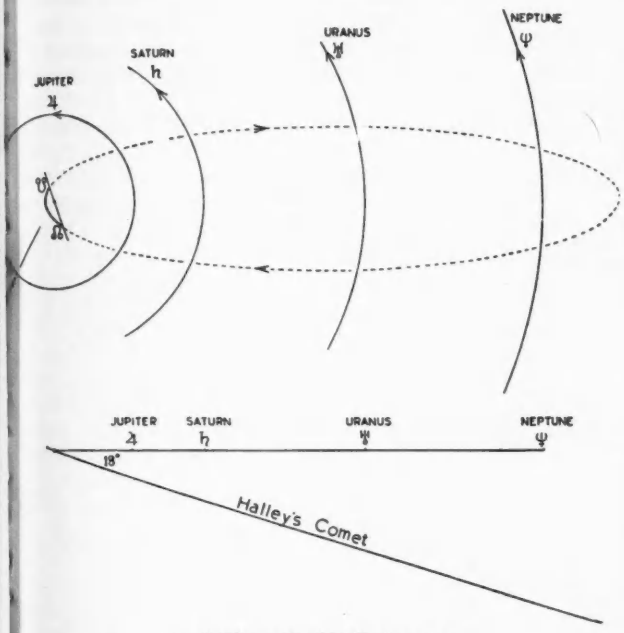


FIG. 2. The orbit of Halley's comet.

METEORS

Meteors, popularly called shooting stars, may be seen any clear, dark, moonless night. They usually appear as brief streaks of light, which may be visible for only a fraction of a second. This effect is caused by interplanetary material vaporising as it enters the Earth's atmosphere at high speed. An unusually bright meteor may leave an "enduring train" in the sky or it may appear to break up and possibly explode at the end of its flight.

Not much serious work was done on meteors until a spectacular display occurred on November 12, 1833, when meteors were seen to be falling at a rate more usually associated with snowflakes in a snowstorm. It was noticed that the meteors appeared to issue from a point in the constellation Leo. This was quickly realised to be a perspective effect, meaning that all the meteors were travelling along parallel paths in nearly the same orbit. The point in the sky from which meteors appear to radiate is known as the radiant. Meteor streams are usually named after the constellation in which the radiant is found, and the November meteors are called the Leonids.

In addition to the meteors observed in meteor showers and streams, there occurs a continual background of "sporadic" meteors. Their origins are obviously even less certain but, as meteor streams occur with such varying strengths, it is probably reasonable to assume that most sporadic meteors were originally members of streams, since dispersed so widely as to be no longer recognisable. Particles from the collision of asteroids are also a possible source for some sporadic meteors.

At one time, sporadic meteors were thought to move in hyperbolic orbits (that is, they came from outside the Solar System), but results from improved observing techniques have not confirmed this.

Visual Observations. A visual observer notes the beginning and end points of a meteor's path in the sky. The brightness of the meteor and the observed time are recorded, and also an estimate of the duration of its flight. The observations of a single observer can provide meteor radiants and meteor frequencies. Observations, by two or more observers sufficiently far apart, of the same meteor, provide a three-dimensional representation of the meteor's path through the atmosphere. It is essential for the determination of a good orbit that the meteor's velocity be determined with fair accuracy. This means that a good value for the duration of flight is needed. Visual observations are limited in this respect and the first really accurate velocities were determined by photography.

Photographic Observations. Two cameras, each aimed at a point high in the atmosphere and sufficiently far apart, can provide a good three-dimensional picture of a meteor's path in just the same way as two visual observers can. Apart from the obvious advantages of being impersonal, more accurate, and providing a permanent record, photography can also be used to provide accurate meteor velocities. By the rotation of a shutter in front of a camera a long exposure can be interrupted many times. The star images are not affected by the interruptions, but any meteor trail registering on the plate will be broken into short segments. If the rate of rotation of the shutter is known, the duration of flight can be found by counting the breaks in the trail. The use of two cameras provides the distance of the meteor and so its velocity is easily calculated.

Systematic work with two cameras was started in 1936 by the Harvard Observatory. Since 1952 they have been using very fast Baker Super-Schmidt cameras at two sites in New Mexico. Each camera covers an area of the sky 55° in diameter and works at f/0·7. On the average, they record one meteor for each eighteen minutes of exposure time.

From the data supplied by these cameras it has been possible to calculate a large number of meteor orbits. These show that almost all meteors, including sporadic ones, were moving in periodic orbits before they entered the Earth's atmosphere.

These observations also yield values for the deceleration of meteors in the atmosphere. On the basis of reasonable assumptions about the atmosphere, it has been possible to obtain values for meteor masses and densities. Both are surprisingly small; it seems that most meteors have masses

of a few grams or less, and many have densities less than that of water. They can be visualised as being very porous and fragile and ready to crumble under low pressures.

These investigations are being carried out under Whipple's supervision, and the results obtained so far have led him to suggest his "comet-model".

Radio Observations. The war-time developments in radar have provided meteor astronomy with a powerful new tool. Owing to a meteor's high speed (12 km./sec. to 72 km./sec.) relative to the atmosphere, it strips electrons from the atoms in the column of air through which it passes. It is the resulting expanding column of electrons which is detected by radar; the meteor itself is far too small. The advantages of the radio technique over all the others are that it makes possible the observation of meteors as faint as magnitude 9 or 10 even when the sky is completely cloudy, and, most important of all, even during the daytime. Orbits can also be obtained from radio observations, and many important daytime meteor streams have been discovered. Some of them are quite as strong as any of the regular night-time streams. One stream, the Taurids, moves close to the Earth's orbital plane and can be observed visually at night-time in November and by radio observation during the day in July. Many meteors seem to move in orbits fairly close to the Sun, like these, near the plane of the planets' orbits. There is a strong possibility that they are associated with the Zodiacal Light and the Sun's corona.

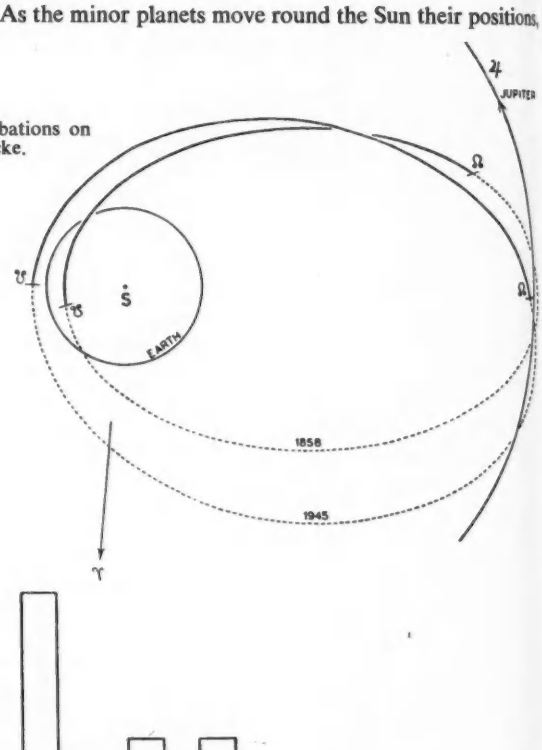
MINOR PLANETS

Reliable orbits for more than 1600 minor planets have been calculated up to the present time. The majority of these are between the orbits of Mars and Jupiter and not very inclined to them. All the minor planets move in the same direction as the major planets. Viewed from the Earth, they nearly all appear to move within 30° of the ecliptic (the projection of the plane of the Earth's orbit on to the Celestial Sphere).

The first minor planet, Ceres, was discovered in 1801 by Piazzi at Palermo, and minor planets have been discovered at an ever-increasing rate since then. For ninety years all the discoveries were made visually, by checking each star seen in a telescope against catalogues and charts. It is their stellar appearance in a telescope which led minor planets to be given the alternative name of asteroids. In 1891 asteroid 323 was discovered photographically by Max Wolf at Heidelberg, and from that time photographic methods naturally replaced the extremely laborious visual method.

As the minor planets move round the Sun their positions,

FIG. 3. The long-term effect of Jupiter perturbations on the orbit of periodic comet Pons Winnecke.



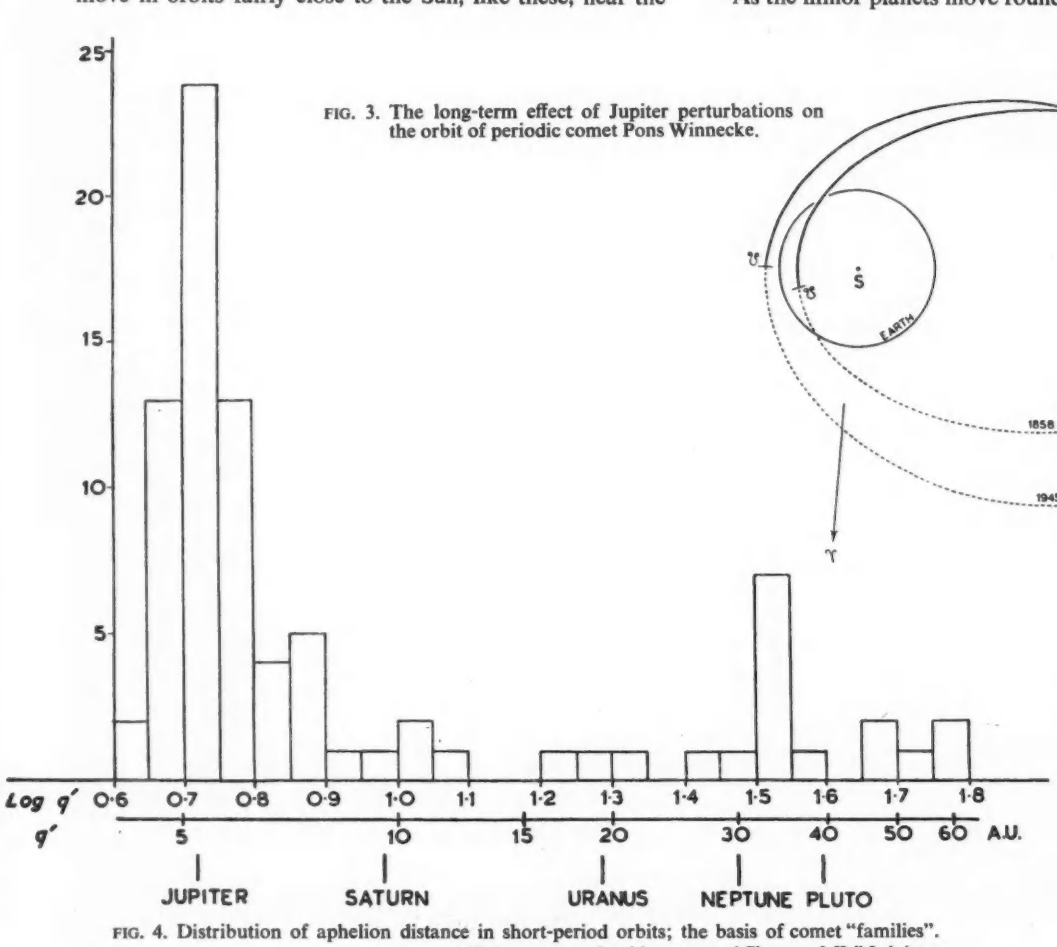


FIG. 4. Distribution of aphelion distance in short-period orbits; the basis of comet "families".

(All diagrams reproduced by courtesy of Chapman & Hall Ltd, from J. G. Porter, "Comets and Meteor Streams", London, 1952)

relative to the fixed stars, change slowly. This was the basis of the visual method of discovery. If a photographic plate is exposed for an hour, say, guiding carefully on a star, all the stars on the plate will appear as small discs. Any minor planet which happens to be in the area covered by the plate will register as a fine line, due to its motion during the exposure. If a suitable camera is pointed towards the ecliptic, a number of minor-planet trails may be obtained on the same plate.

Minor Planet Survey. Recently a systematic survey of minor planets was completed by Kuiper at the Yerkes Observatory. The survey was carried out with a 10-in. aperture f/7 camera, recording minor planets down to magnitude 16·5. By means of searching the plates independently of previous knowledge, it was possible to assess the efficiency of minor-planet discovery. Very few planets brighter than magnitude 14·5 can remain to be discovered. Accurate positions and magnitudes were measured for all the minor planets recorded on the plates and a number of new ones were found. Also a great deal of new material has been made available for statistical analysis.

Keeping track of 1600 minor planets, allowing for planetary perturbations, publishing predicted positions, and calculating orbits for new discoveries is no light task. The Institute of Theoretical Astronomy at Leningrad and the Minor Planet Centre at Cincinnati, using electronic computing machines, are, however, able to carry out all this work in a routine manner.

If a diagram is drawn of the number of minor planets with different periods, gaps become obvious. They occur just where the periods of the minor planets and that of Jupiter are commensurate. Though the attractions of Jupiter are likely to be important, the exact mechanism whereby the gaps are formed has not been satisfactorily explained. As well as gaps, groups or families of minor planets also occur. For instance, two interesting groups of minor planets, called the Trojans, about a dozen of which are known, have the same period as Jupiter. One group moves near Jupiter's orbit, but 60° in advance of the planet, and the other group moves 60° behind. The motion of the Trojans is quite stable, apart from attractions by Saturn, which cause them to oscillate about the 60° mark. This is one of the stable solutions of the so-called "Three Body Problem" and was discovered mathematically by Lagrange in 1772. Its natural occurrence was not known until 1906, when the first Trojan was found.

Some minor planets have special interest as they move in unusual orbits and can make very close approaches to the Earth. This enables one to determine their distance very accurately, and hence to calculate the whole scale of the Solar System. The minor planet Eros was used for this purpose in 1931. Icarus is another interesting case. It is so named because it passes closer to the Sun than any other known planet. It can also pass very close to both Mercury and the Earth. By chance, in 1968 Icarus will pass close to Mercury and then shortly afterwards will pass close to the Earth. The deviation in the motion of Icarus caused by Mercury will probably provide a better value for Mercury's mass than has been obtained before.

The light from a minor planet is reflected sunlight. The magnitudes of minor planets fluctuate and accurate photometric work shows that most of them are irregularly shaped bodies which rotate in a few hours. These and other considerations have led to the suggestion that minor planets were formed from a much larger body or bodies, broken up by collisions. The proof or otherwise of this proposition will not be easy. The orbits, which in the case of comets are able to provide clues to their origin, are not likely to be much help in this respect for minor planets. Perturbations, particularly by Jupiter, have disguised completely their original forms.

CONCLUSIONS

It can be seen that the orbits of comets, meteors, and minor planets are far better known that anything else about them. Even so, there is a great deal that could be done with the orbital data already available. For instance, although a fair number of periodic comets have made many returns to perihelion, very few indeed have had their movements completely analysed, including the effects of planetary perturbations. Still fewer have had their orbits extended backwards in time for a number of centuries. The electronic machines, already available, could deal with a problem of this magnitude. If enough comets were dealt with in this fashion, we might obtain some clues to their origins. A similar treatment for well-observed minor planets might also be instructive.

Current progress in space-vehicles shows that it cannot be long before man himself makes his first journey away from the Earth. Before he does so, he will need reassuring about the hazards from impact with interplanetary material. Research with unmanned vehicles containing devices for counting particle impacts has already begun. By sending these vehicles to different parts of the Solar System, a fairly complete picture could be formed of the distribution of interplanetary dust—there is likely to be a large amount of it.

From outside the harassing atmosphere an astronomer will be able to observe under superlative conditions. The consequent improvements in photometry and spectroscopy will help in the study of the bodies considered here as well as all others. There will also be a much greater chance of discovering comets, novae, and so on, which are otherwise badly placed from the Earth.

Studies of the Solar System are out of fashion these days, and, apart from radio work, far too little is being done in this country to solve the remaining problems. Work in the field of interplanetary bodies has been stimulated in the U.S.A. and the U.S.S.R. by the beginnings of space-travel, and pure astronomy should benefit greatly from this drive. Now that this country is becoming more interested in space, perhaps we can hope for a similar growth in the research on comets, meteors, and minor planets here as well.

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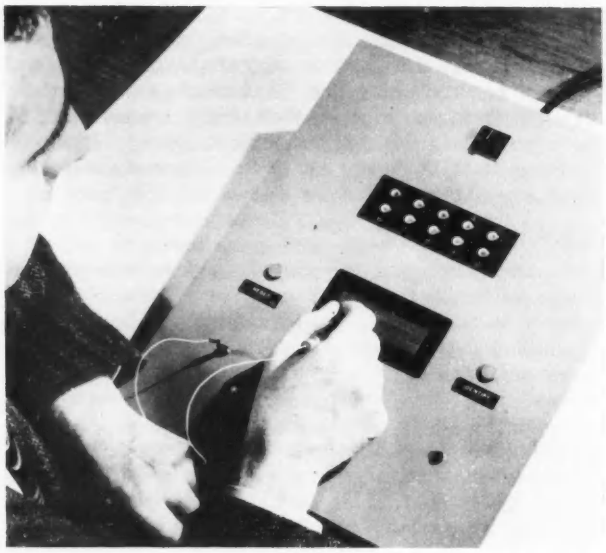


NEW SCIENTIFIC INSTRUMENTS

***A new feature, which will review instruments of all kinds as a service to the readers of* DISCOVERY.**

The Bell Telephone Company Handwriting Reader being demonstrated by the inventor, Leon D. Harman

The biggest instrument in the news at the moment is an **Electronic Network Analyser**, ENA for short, which has been built by the Electrical Research Association. ENA has a thousand valves and 430 separate network units which can be inter-connected as desired, using a plug board, to build up complex systems. ENA operates with sine of square waves whose frequencies can be varied continuously over a range of 100 : 1—from 159·2 c/s to 15·92 kc/s. It will operate either on single or three-phase systems and is accurate to about 1%. The results are normally read on dials, but cathode ray tube monitors can be switched into circuit for checking purposes.

Although ENA was designed to solve electrical network problems, for example, it has obtained the figures required to write the specification of a new circuit-breaker to ensure that arcing extinguished itself, it can also be used for certain mechanical or thermal problems. ENA can be hired by ERA members for £30 a day, or by non-members, when it is available, for £40.

Another step has been taken to provide an input system for a **computer used for industrial purposes.** Bell Telephone Laboratories have built an experimental machine which can "read" ordinary handwriting. As yet, the device is simple and has a "vocabulary" of but ten words, namely, "zero" to "nine" spelt out in connected handwriting, but it is suggested that more sophisticated machines are contemplated.

To use the handwriting reader, a writer moves a metal stylus over a special surface (see photograph) just as if he were using an ordinary pencil. Then, when he touches a button labelled IDENTIFY, one of a bank of numerals corresponding to the number he has written lights up. The reader identifies the shape of the word by selecting particular pattern features such as the length of the word, the dotting of the "i's" and the number and position of vertically extended letters such as "h" and "g". On a test of 1000 words written by twenty persons, the machine made only thirty errors, a score that BTL believe they can improve by minor changes.

In the medical field there is a new **blood pump** for heart surgery. This is used during profound hyperthermia—the cooling of patients during heart surgery to avoid brain damage. The pump is coupled to a heat exchanger to cool and reheat the blood. During cooling, it forces blood into the lungs for oxygenation. The pump element is a replaceable piece of rubber tubing.

Research is going on in Canada to detect cancer by measuring the heat produced by the increased metabolism of cells undergoing accelerated division. The instrument employed is an **infra-red camera.** As the maximum radiation has a wavelength of about 9·5 microns, the direct formation of an image is impossible. The field of interest is therefore scanned by mechanically oscillating the optical system to produce a 275-line picture on polaroid film. It has been found that good thermal pictures of the human body can be produced in five minutes with a temperature-sensitivity of 0·5°F. Twenty-six patients, who subsequently developed breast cancer, showed an average temperature rise in the area of the tumour or the ipsilateral areola of 2·27°F.

New materials and new techniques in instrument technology have many applications. In this context, a **new alloy** for watch and instrument springs is of interest. Called "Fortinox", this alloy is stainless, unbreakable, and does not lose power with age.

Improvements in **transistors** continue to be announced. Siemens Edison Swan Ltd have added high-speed switching transistors to their range with minimum gain/bandwidth products of 20, 40, or 60 Mc/s, while RCA make a germanium p-n-p drift transistor for RF amplification at 50 Mc/s or oscillation up to 125 Mc/s. GEC, whose production of transistors and diodes is now 120,000 per week, have perfected a cold welding technique for sealing transistor envelopes.

Most lecturers have wrestled with the problem of producing a really large **spectrum for demonstration.** One of the manufacturers of Merton-NPL diffraction gratings now sell for £6 a right-angle prism with a 15,000 lines/in. grating cast in plastic on the hypotenuse. Fitted to a standard slide projector with a slit in the slide carrier, this prism will project a 4-ft. spectrum.

A. GARRATT

MANUFACTURERS

Electronic Network Analyser. Electrical Research Association, Leatherhead.

Handwriting Reader. Bell Telephone Laboratories, New York 14.

Roller Blood Pump. Siemens Edison Swan Ltd, London, W.C.2.

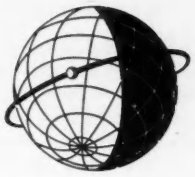
Infra-red Scanning Camera. Radio and Electrical Engineering Division, National Research Council of Canada, Ottawa.

Fortinox Alloy. United Steel Companies Ltd, Sheffield 10.

Transistors. Siemens Edison Swan Ltd, London, W.C.2; RCA Great Britain Ltd, Sunbury-on-Thames; General Electric Co., London, W.C.2.

Spectrum Production. Paton Hawksley, Bristol.

GEOPHYSICS AND SPACE RESEARCH



By ANGELA CROOME

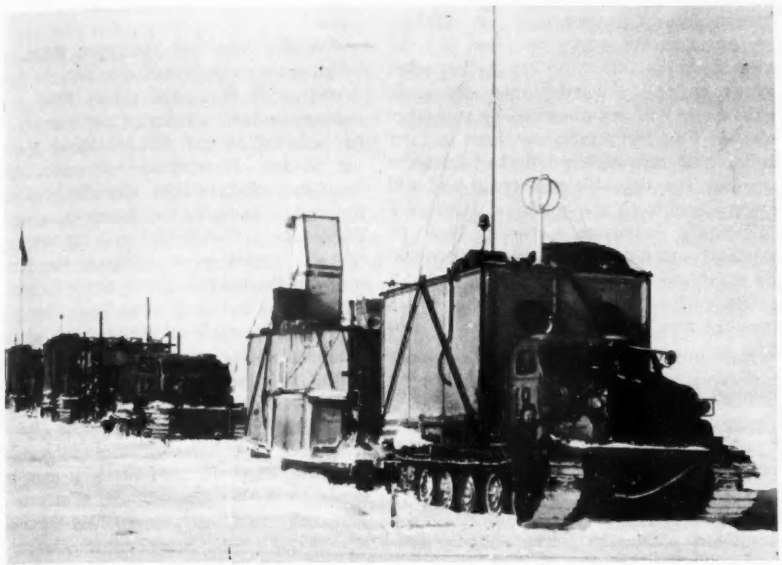


FIG. 1. The sleigh tractor train on its way to the Pole of Relative Inaccessibility.

Russians Start 4000-mile Journey

On November 6 the Russians set out on their remarkable attempt to make a 4000-mile crossing of Antarctica at right angles to Fuchs's route, through the least known and most hostile terrain of the whole continent (see DISCOVERY, 1958, vol. 19, No. 11, p. 474). The official starting-point was the inland sub-station of Komsomolskaya, 500 miles from the coast. A tractor-train which left the coastal base of Mirny at the beginning of October reached and reopened Komsomolskaya a fortnight later (the sub-station had not been in operation during the winter season). Stores were cached and an air-strip made ready for the arrival of heavy air transports with further equipment for the main part of the journey. The traverse party proper set out from there with 400 tons of stores and equipment, conveyed on ten sledges and with two track-laying vehicles in support. The whole expedition was led by three of the most powerful of the newly developed Russian snow-tractors, the Kharkovchankas, which are about the size of a Green Line bus. These huge vehicles are specially designed for operation in the Antarctic interior where conditions of soft, loose snow and loss of engine compression due to great altitude prevail. This is the Kharkovchankas snow-tractor's first season in the Antarctic (see Fig. 1).

A team of seventeen scientists accompanied the expedition. On the first leg of the journey, from Komsomolskaya to Vostok, a glaciological expert from Moscow University, Prof. Boris Saveliev, headed the scientific team.

The full traverse and the associated seismic programme is expected to take two Antarctic seasons to complete. The Russians have no need to rush. There is no Amundsen racing them for the honour of "first there". In any case, the Soviet Union conquered the last and remotest south pole, the "pole of relative inaccessibility", last March. A fortnight's residence was enough. They raised the Russian flag, erected a statue, and pulled out.

This pole lies at about 12,000 ft. in the midst of an appalling plateau, thought to possess the coldest temperature and worst weather anywhere in the world. The yearly *average* temperature, the Russians report, is −50°F. Apart from the effect on engine compression, the air is so thin that men must have frequent whiffs of oxygen to keep them going. It has taken even the hardy Russians three years to reach this desolate spot.

The project now launched is to link three of the south poles where stations have been established, by a probe from Mirny on the Antarctic's Pacific coast, and another from the new Soviet station, Lazarev, on the Atlantic coast (see DISCOVERY Map of Antarctic Research, December 1959). The poles involved are the Geomagnetic Pole ("Vostok"), occupied by the Russians; the Geographic Pole ("Amundsen Scott"), where the Americans have a base; and the Pole of Inaccessibility, where the Russians will reopen their last year's camp.

The triangle formed by connecting these points represents a substantial part of Antarctica never before explored; it will be thoroughly surveyed and the underlying rock located and mapped by seismic means. This should finally establish whether Antarctica is one continent or two, or is, alternatively, a loose archipelago of islands covered by a cap of ice several miles thick.

In the course of this undertaking the Russian expedition will reach the South Geographic Pole from a direction never before attempted—from the Pacific. It is not clear whether this part of the journey will be completed during this season's operations or will start off next season's effort.

Looking at the Weather from Above

The first meeting of an international panel of experts on observing weather from artificial satellites took place in Geneva in November under the auspices of the World Meteorological Organisation. The four meteorologists that make up the panel come from Britain, Australia, the U.S., and the U.S.S.R. (though the Russian member was prevented from attending the November meeting by illness).

It is a matter for speculation that the Russians have so far included no meteorological experiments in their roomy space-vehicles. They do, of course, have a substantial "meteorological rocket" programme. The Americans have both the most extensive plans and the most actual experience so far in studying meteorology from satellites. There are at least three distinct schemes at present in hand. Three American meteorological "packages" have already been placed in orbit: the cloud-cover experiment, sponsored by the Weather Bureau, carried in the February 1959 *Vanguard*; the Space Technology Laboratories' cloud-cover experiment

included in the August "paddlewheel" satellite; and the heat-balance experiment in the October *Explorer VII*, which was instrumented by Prof. Suomi of Wisconsin's group in consultation with the Weather Bureau. The elaborate *Tiros* project, initiated by ARPA, which is to monitor cloud-cover by a specially developed TV system, is expected to be off early this year.

The most promising of the studies launched so far is the one we have heard least about, that designed by the Wisconsin group. It is directed to measuring the tiny changes in global heat-balance that have a long-term effect on weather, and may even be bringing about changes in the overall world climate. The large NASA satellite, in which it got off eventually after more than a year of false starts, is expected to be in orbit for ten years. Three small spheres about the size of ping-pong balls placed at the end of spines projecting from the "equator" of the stabilised satellite are sensitive to different ranges of thermal radiation. The net result gives the incoming solar radiation, the reflected solar radiation, and the radiation in the infra-red region which comes from heat absorbed by the Earth and the atmosphere. Prof. Suomi is understood to be pleased by the way the equipment is working. The instrument is keeping within the temperature tolerances allowed for and a check on its reliability occurs every sunrise. As the Sun reaches the satellite the recorded output temperature rises sharply; at sunrise on Earth a few moments later the heat-balance reading from the satellite rises again, even more sharply.

The other American approach to observing weather from a vehicle passing above it is to use the distribution of the Earth's cloud-cover as a weather guide. The first attempt to do this, in the spring-launched *Vanguard*, was vitiated because the satellite was not successfully "despun" but continued to revolve at nearly 200 r.p.m. and was also tumbling, so that no identifiable picture of cloud-cover or anything else emerged. The second attempt, instrumented quite independently by the Space Technology Laboratories, was carried in the August "paddlewheel" satellite (*Explorer VI*). Curiously, the U.S. Weather Bureau did not even know of the existence of this project till the announcement of the successful launching. In due course, amid considerable Press acclaim, a picture purporting to be part of the Pacific Ocean and its cloud-cover as seen from 17,000 miles up and taking forty-five minutes to transmit, was published. The quality of the picture was made to look rather absurd a month later, when the *Lunik III* photograph of the back of the Moon, photographed from 40,000 miles away and then over 200,000 miles from Earth, appeared.

It is now understood that the "paddlewheel" cloud-cover apparatus was a run-in for a study not of the terrestrial atmosphere but of planetary atmospheres.

Photographs of the Earth made from the recovered *Atlas* nose-cone instrumented by GEC and fired in August over the Atlantic, yielded a valuable piece of meteorological information. A "front" far out over the ocean was well defined, also a ripple effect on its upper edge, which American weather-men say could not be and was not observed by any other means. This has confirmed them in their belief that monitoring cloud-cover from satellites is a valuable endeavour and will bring benefits to the world at large if a sufficiently extensive network both of satellites and ground-analysis stations can be organised.

One of the objects of the recent Geneva meeting was to consider how best to do this.

Second Electro-jet Current over Equator

Reduction of IGY magnetometer data from *rockoon* flights made from shipboard near the Equator by State University of Iowa scientists has revealed a second electric current, positioned like a doughnut above the Earth at these latitudes. (See DISCOVERY, 1958, vol. 19, No. 5, p. 208.)

These electro-jets, as they are called, are associated with the region of peak ionospheric conductivity at about 100 km. and flow from west to east. Their width appears to be about 300 km. During the SUI *rockoon* flights the altitude of the lower edge of the lower and weaker electro-jet was found to be 97 km. and extends up to 110 km. Its maximum amplitude (close to what may be called the "core") was nearly 20 amperes/sq. km. The upper electro-jet was observed at 117 km. and was not completely penetrated when the rocket began its descent at 129 km.

A flight to the north of the main electro-jet penetrated a smaller current sheet only 4 km. thick at 104 km. high. This flowed in the opposite, east-west, direction to the main system.

These observations broadly confirm the "dynamo theory" of magnetic field variations as observed at the Earth's surface. This supposes that charged atmospheric particles move in tidal winds across the magnetic field lines, thus inducing electromotive forces in the direction perpendicular to the Earth's magnetic field. Positive and negative particles move in opposite directions and so set up electric current systems in the atmosphere. The tidal winds are related to the Sun's movement across the sky, so the electro-jets are a daytime phenomenon. Considerable variations in the altitude and density of the currents were predicted and have now been observed.

British Space Experiments—Some Progress

How are British scientists interested in performing experiments from the American *Scout* satellite getting on with their plans?

No decision has yet been taken on which experiments will go into the first *Scout* ready (expected off in 1961), and indeed the final choice of experiments to be included in the different fields is not yet settled. Nevertheless it seems high time to report on the way thoughts are moving in some of the university groups concerned. No doubt our readers are curious about what progress has been made in the six months since the Government statement, following Prof. Massey's space mission to Washington.

In fact, some of the British groups involved in the *Scout* project have already progressed far enough to have prepared laboratory test "lash-ups" of the experiments they have put forward to the space research selection committee. It must be made clear that none of the experiments here discussed has yet received the final "go-ahead"; this must come ultimately from the Americans. Even when this has been received many modifications may be expected in equipment design, and priorities may remain flexible until quite a late date. This month a small party of British space researchers are to visit Washington to gain clearance on some of these points from the National Aeronautics and Space Administration.

Probably one of the first space-vehicle devices ready for testing will be that of the Cosmic Ray Group at Imperial College. The "first draft" apparatus is quite small; it might be expected to weigh 2 or 3 lb. in a satellite version.

The object is to study the way in which primary cosmic ray intensity changes with time and to relate these changes to the variation in secondary cosmic rays high up in the Earth's atmosphere. The experiment therefore involves simultaneous cosmic ray measurements by satellite and by jet aircraft and possibly the use of balloons as well. The Van Allen radiation which will be encountered at satellite heights provides a complication in instrumenting the experiment but the detector intended for the satellite observations will be able to discriminate between cosmic ray and Van Allen particles, because it will respond only to the heavier atomic nuclei, from carbon upwards. The Van Allen component is assumed to be predominantly protons (nuclei of hydrogen) and electrons.

Such an experiment would ultimately enable variations of cosmic ray intensity *above* the atmosphere to be satisfactorily measured by monitoring cosmic radiation at aeroplane altitudes. This in turn will permit interpretation of the factors that affect cosmic ray intensity; these must be the magnetic fields in interplanetary space which are associated with the action of the Sun. But at present the mechanism of the Sun's magnetic action far from its surface is not at all clear. The recent announcement as a result of work carried out by Drs Harold and Horace Babcock in California, that the Sun reverses its field completely during the 22-year solar cycle, bears on this.

Prof. Martin Ryle's radio astronomy group at Cambridge has also got quite far in its thinking about useful satellite experiments. This group has also been thinking about cosmic rays. Since these particles move at close to the speed of light they produce synchrotron radiation which has distinctive radio-frequency characteristics. But these radio-frequencies cannot penetrate to aerials on the Earth's surface. By flying a directive radio aerial at satellite heights it might be possible to locate the direction or directions from which the cosmic rays were most intense and thence learn something about their origin.

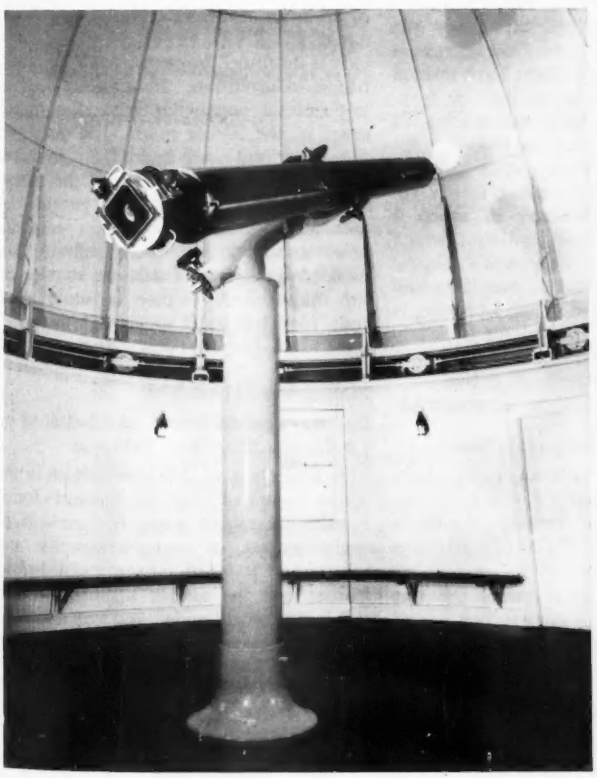
This group also has an interest in measuring the density of interstellar gas near the Sun, which might be done by monitoring the very low frequency radio-waves (about ½ Mc/s). Again such very long wavelengths cannot penetrate to the ground, so they require a space vehicle to be observed. To get worth-while data on interstellar gas by this means, an accuracy of 20% is required from the apparatus.

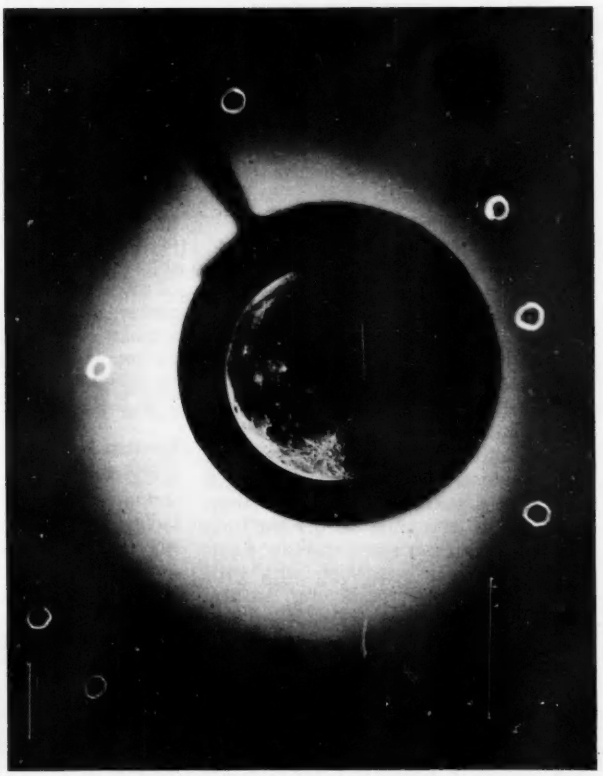
Signals from Other Worlds?

The time has come to see whether we are the only intelligent beings in this corner of the universe. This can be done readily and quite cheaply. Not by attempting enormously elaborate, centuries-long space-travel, but by monitoring the characteristic hydrogen-line frequency of radio-waves from space at ground-level on the large radio-telescope already available. These, the Jodrell Bank giant dish for instance, are able to penetrate to a distance of 200 million light years. There is a star population offering suitable candidates for the support of life numbering 100 within fifty light-years of the Earth. These would be the objects to scan first for the appearance of artificial signals, a project that might take up to five years but need not take longer.

This is the challenging proposal put forward by Giuseppe Cocconi and Philip Morrison of Cornell University in a recent issue of *Nature*. Prof. Morrison has spent the last few months at Imperial College. The writer has been able to discuss his views with him. The intrinsic interest and the philosophical implications of such a search, if it proved successful, can hardly be over-estimated. Though Jodrell Bank has not yet indicated any particular interest in this line of investigation, the new director of Green Bank, West Virginia national radio observatory, is planning to initiate such a radio search on the 74-ft. radio telescope there with the beginning of the New Year. "The probability of success is hard to estimate; but if we never search, the chance of success is zero." Prof. Morrison has put the matter with a simple emphasis.

FIG. 2 (*left*). The Markowitz Dual-rate Moon Camera used at the U.S. Naval Observatory, Washington, D.C., for latitude and longitude determination. Attached to the 8-in. refractor telescope (162-in. focal length), the camera measures accurately the position of the Moon in relation to the stars (some seen ringed in Fig. 3) which leads to precise fixing of the Earth's co-ordinates free of the distortion of gravity. FIG. 3 (*right*). An unusual picture of the Moon taken by the Markowitz camera.





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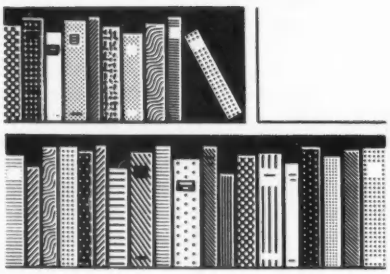

Physics of the Stoics

By S. Sambursky (*London, Routledge & Kegan Paul, 1959, 153 pp., 23s.*)

"The significance of some of the basic scientific hypotheses and concepts is largely determined by their intrinsic functional and structural elements, irrespective of the historical period in which they took shape," writes Prof. Sambursky (p. 35) in his fascinating and scholarly study of the physical and logical ideas of the Stoics (4th to 1st century B.C.); and this methodological credo provides the driving force as well as the genuine interest for the historical study of older scientific ideas. The basic facet of Stoic physical thought is the development of the concept of the continuum as being the fundamental thought-unit in terms of which to represent the major physical phenomena. It is true, as Prof. Sambursky stresses, that the continuum hypothesis, like its chief rivals, the theories of the atomists and the approach of Aristotle, was "essentially speculative, based on theoretical conceptions and developed along purely epistemological lines" (p. 44), lacking a properly worked out experimental foundation. But the more we learn about the growth of scientific ideas, the more we realise the importance of the first sketch, of the general viewpoint, gradually delineating specific scientific problems and formulating the questions that are to be asked. Just for this reason it is fascinating to find that field theory, exactly like atomic theory, had its Greek forerunner, even if the evidence of its influence on 17th-century developments is less definite for the continuum case.

The author traces out the major idea of the pneuma, a sort of life-force, active principle, a universal bond, sometimes conceived of as a universal binding force or tension, sometimes as a repulsive force, and discusses its connexion with what was called "hexis" (structure; process; habit; physical state of the body), a difficult conception which apparently did many duties. A number of anticipations of later ideas are mentioned: the close connexion between pneuma and the modern field of force, which Sambursky believes to have been one of the most important innovations in the physical philosophy of the Greeks who hitherto had only considered forces as pushes or pulls. In similar fashion, the pneuma proves to be an anticipation of the 17th-century physical ether. Among the most interesting discussions are the comparison between atomistic, Aristotelian, and Stoic theories of "mixture" (which includes the concepts which we denote by such terms as "compound" and "solution"), contrasting the Aristotelian "potentially-actuality" account with the perhaps equally difficult Stoical notion of each particle containing a share of the rest. When this is considered, however, together with the assumption of continuous forces of tension within the body (the most significant difference between this and atomic theory) we realise that here was a doctrine which in its extreme subtlety (and because of its necessary vagueness) was far ahead of its times.

The influence of these ideas in the fields of logic and mathematics provides further fascinating themes; what a pity, as the author remarks, that the records that have come down should have been so sketchy and so often have been compiled by hostile hands.

There are useful translations of texts, and altogether the scholarship is a model to be followed by all who have the development of the history of science at heart. If anything one might have wanted fewer attempts to insist on the "modernity" of these ideas, and the tracing of essential parallels with later thought; the evidence is after all somewhat tenuous, and the content of the older theory together with the framework in which it occurs, rather vague—a criticism which applies particularly to the author's account of the Stoic conceptions of causation and conservation doctrines. This, however, is a minor complaint. The volume is clearly an important addition to the literature on the subject and deserves high praise.

G. BUCHDAHL

Russian Journal of Inorganic Chemistry

(*Published by The Chemical Society. Subscription rates: ordinary, £30 per annum, including postage; for libraries of university and technical college, £22 10s. per annum, including postage*)

A feature of chemistry during the last two decades has been the marked rise in the volume of literature written in the Russian language, so that any chemists who are unable to read these texts are becoming more and more aware of their loss. To meet this need the Department of Scientific and Industrial Research has given financial support to the Council of the Chemical Society to enable them to provide a cover-to-cover translation of *Zhurnal Neorganicheskoi Khimii*, the only Russian journal devoted entirely to inorganic chemistry. The translations are carried out by a team of experts and are edited by Prof. P. L. Robinson, together with an impressive list of other inorganic and theoretical chemists. It is to be hoped that this will be the first of a number of Russian chemical journal translations which will go far to ensuring mutual understanding between chemists separated by barriers of language. The first copy of the translation is attractively bound and printed and will doubtless be welcomed by all inorganic chemists.

A. W. JOHNSON

Oxford Plastic Relief Maps

Series 2, Map 1, Great Britain and Northern Ireland (*Oxford University Press, 50s.*)

This map, on a scale of 1 : 1,000,000, is considerably larger than those of the earlier series, each of which covered a continent. In addition, it is coloured to show sea and rivers (blue), moorland and heath (light purple), woods (green), and built-up areas (red), and shows the names of counties and towns, and county boundaries.

It is doubtful, however, if all this additional information, though useful, does not detract somewhat from the simple relief of the earlier maps. The purple of the moorland and heath, for instance, tends to kill the modelling of the mountains and hills, the more so because the two features so often almost coincide. One wonders, too, why railways are omitted since main roads are shown—do the map-makers foresee a future when only road transport survives?

J. F. HORRABIN

Bibliografia Marconiana

By Giovanni de Benedetto (*published by La Ricerca Scientifica, 2000 lire*)

This collection of 2662 references to the life and work of Marconi obviously forms a valuable source book for students of every aspect of radio-telegraphy and telephony. It is, of course, published in Italian, but the author appears to have combed a world-wide range of literature for his material. The titles of all the articles quoted are given in the original language. Occasionally there is a brief note, in Italian, on the leading features of the articles or reports mentioned.

J. H. M. SYKES

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Health in Industry

By Donald Hunter (*Penguin Books, 1959, 288 pp., 4s.*)

This is an important addition to the Pelican Medical Series written by Dr Donald Hunter who has a world-wide reputation in this field of medicine. It is a difficult subject to select for publication in a "popular series" because much of the material will be specialist and will be clearly understood only by those working in that industry, and by scientists and doctors, but the author emphasises that more than half the book is free from technical terms and should prove interesting to the general public; for their benefit he has prepared a useful glossary of technical terms.

The chapter on the history of industrial medicine is extremely interesting. The author's study of Ramazzini, who was born in Italy in 1633, and became known as the Father of Occupational Medicine, is fascinating. He reminds the reader that industrial medicine was born in England as a direct result of the Industrial Revolution and that "English doctors were the first to assume responsibility for the health of the worker in industry". He pays well-deserved tribute to Legge who, in 1898, was appointed the first medical inspector of factories. The chapter on accidents is also of considerable value. The author maintains that a reduction of not more than 10% in the accident rate can be expected from the provision of safeguards alone; he eminds us that many accidents are of psychological origin and that possibly 25% of workers are accident-prone. The second half of the book is concerned with the various poisonings and hazards to be found in industrial employment and contains a great deal of valuable technical information. The sections on lead poisoning silicosis, and occupational cancer are particularly interesting.

Dr Hunter stresses the continuing need for an understanding of human relationships in industry. He says that "the factory medical officer should never allow his special technical knowledge to assume greater importance than his knowledge of doctoring in the broadest sense of the term . . . and should follow his various activities with a constant regard for social values". He reminds the reader also of the significant finding of the Hawthorne experiment which related industrial output to working conditions.

This important book should be in the hands of all doctors, social workers, and others, including managements, who are concerned with industrial health. Much of it will prove interesting to the general public. Dr Hunter rightly pays tribute to what has been achieved in Great Britain in industrial medicine, and he urges even greater efforts in the future. As one would expect, this book has been well produced and it will serve as a distinguished member of the Pelican Medical Series.

C. A. BOUCHER

Reading German for Scientists

By H. Eichner and H. Hein (*London, Chapman & Hall, 1959, xi+207 pp., 30s.*)

The faculty of languages has long been known to be a strong force in Queen's University, Kingston, Ontario, and to your reviewer at any rate a good, well-planned science German course coming from there constitutes no surprise.

Although associated with less orthodox methods in teaching German as utility-reading, subject primarily (if not exclusively) to scientists and engineers, the reviewer welcomes this book warmly. It fulfils well one requirement in this connexion, in presenting the subject in an attractive and easy fashion.

The method is conventional and well worn; obviously both authors have been able to draw upon years of experience in the field. This is clear at one glance from the selection of what amounts to a basic scientific German vocabulary, for instance. For students really wanting just that reading knowledge, this book is certainly a short cut. The extracts are from recent readings in Chemistry and Physics (in that order, presumably to reflect the present-day frequency and spread of publications), and the vocabulary is made easy, perhaps too easy, by providing glossaries for each passage, a complete word-list with meanings in the back, and a reference index which may have saved the word-list appendage.

But there is no harm in erring on the generous side. The science student, harassed by laboratory and lecture work, will be grateful, and even if taken as a refresher by those who did their German some years ago, the slim volume will not fail its users.

J. HORNE

Non-Destructive Testing

By J. F. Hinsley (*Macdonald & Evans Ltd, 9 in.×5¾ in., 492 pp., line and half-tone illustrations, 75s.*)

It is perhaps first desirable to define non-destructive testing: and the author wisely does this for us in his very first paragraph:

> "Non-destructive testing may be defined as the science of examining materials or manufactured articles in order to determine their fitness for certain purposes without impairment of their desirable properties."

The science of non-destructive testing has emerged rapidly in the last decade as a study of considerable complexity, since

so many other branches of science are brought to its aid. For example, the author deals with ultrasonic methods; radiological techniques, including the use of radioactive isotopes and x-rays; magnetic flaw detection; and diffraction measurements, to mention only a few scientific techniques he and his colleagues in this field have harnessed for their own special purposes.

The book gives an exhaustive survey of this increasingly important industrial activity. It is clearly and simply written and amply illustrated. The author has an easy style and is not afraid, on occasion, to use homely examples and phrases to make his point. For example, in a very wise chapter on safety precautions in laboratories dealing with x-rays and radioactive materials he mentions the two main classes of persons foolhardy enough to risk radioactive exposure. They are, first, the exhibitionist who "regards a radioactive source in rather the same light that a bull-fighter regards the bull—as some object by which his complete unconcern in the face of danger may be demonstrated". Secondly, there is the lazy individual who "justifies such lunacy as the handling of unmounted radioactive sources with unprotected fingers by statements such as 'it's quite safe if you handle it quickly'."

Again, to illustrate the welcome lightness of touch which the author uses at appropriate times, we may quote a few words from his introduction to flaw detection by magnetic methods.

> "For some years the method was known as Magnetic Crack Detection. Later on, perhaps in order to mollify those to whom the idea of cracks in their products was repugnant, the term Magnetic Particle Inspection was coined. The implication that the method deals with the inspection of magnetic particles renders such a title inconsistent with the function of the process it is supposed to represent."

A check of the subject headings in the twenty chapters into which the book is divided against the last five years' references to this subject in *Science Abstracts* shows that among all the voluminous literature and the vast multiplicity of devices brought into the field of non-destructive testing, none has been missed by the author.

If this is regarded as a negative sort of testimonial, it is not so intended, since (in the words of the preface):

> "developments have been so rapid in recent years that such a work [as this book] could have been almost out of date when published. . . . The author, therefore, has dealt at length with the well-established methods and has included such of the newer techniques as show promise of extended utility."

J. H. M. SYKES

Plastics Abstracts

(*Welwyn, Plastics Investigations, 1959, weekly, 10s.*)

This new journal gives abstracting service covering British patent specifications, and articles dealing with the science, technology and application of plastics. These abstracts are published normally one week after publication of the original patent specifications, and within two weeks of the appearance of the articles. British patent specifications are inspected weekly, and 250 periodicals are examined in its preparation. Detailed author, patent, and subject indexes will be published annually. Subscribers' requests for specific information contained in the current year's abstracts will be answered free of charge. The journal is obtained by subscription from the publishers.

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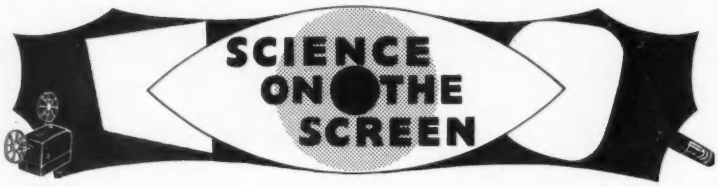


November Television

We have seen during the month of November a considerable output in science television broadcasting.

On BBC there were a series of fifteen-minute broadcasts by Sir Lawrence Bragg, entitled "The Nature of Things" and televised by outside cameras at the Royal Institution. Sir Lawrence has devised some striking models to illustrate atomic and molecular processes. A fine direct display of Brownian movement was successfully broadcast, and what could have been more homely and descriptive than the clever analogy of partners in a square dance used to illustrate chemical valency?

This is ideal science television. It has all the correct ingredients: a compelling personality, a disarming yet most carefully prepared simplicity, beautiful experiments, a narrow restriction of theme and a close concentration on the essentially visual.

On November 26 ITV gave us another of their important Granada Lectures, delivered by Sir Eric Ashby. This was in part an earnest plea for television to bring science to the masses. Sir Eric suggested that by concentrating on the practical techniques and crafts which lie behind so much successful scientific progress, the real significance of science could more readily be brought home to the artisan and to the operative. In all fairness to established broadcasting techniques, it is a fact that this very approach has for some time now been regularly adopted in schools broadcasts, particularly in the ITV schools science broadcasts of John Frankau. Sir Eric is certainly right in pleading for such an approach for popularising science for the adult. To my own personal delight, he was scathing about those hugely organised programmes which try to overpower the viewer with bigger and better machines, with huge computers and vast research teams. As he so penetratingly pointed out, such a programme may well inspire an artisan to mutter "Cripes!", but there the real impact ends.

A few days after Sir Eric Ashby's lecture, BBC, on December 2, put out their much-heralded sixty-minute broadcast entitled "Science International. A world-wide report on Scientific Research. No. 1: What is Life?" It was produced by H. Fisher and A. E. Singer, assisted by a distinguished production team.

This programme almost gave me mental indigestion! It was theatrical, a bit of a nightmare, impossibly overloaded, far too technical in numerous parts, and much too long. It was organised and produced by the Outside Broadcasts section, and time and again I have criticised their adoption of snap titles. A good title can be concise without being catchpenny, and whereas the programme was devoted specifically to the mechanism of the living cell, to give it so profound a title as "What is Life?" was certain to mislead many.

As for the programme itself, we were subjected to a machine-gun rattle of technical terminology throughout the major part of the broadcast. I hurriedly tried to take down some like "in considering RNA and ATP the amino-acid residue activated by ATP is fixed on the ribonucleic acid . . .", etc. Do the producers really think they are being helpful to the millions seeking an answer to what is life if they permit their broadcasters to employ such technical phraseology? And if I have slightly misquoted (which is more than likely since I do not boast any shorthand and the speed was quickfire), will anyone blame me? At one time Raymond Baxter struggled for definitions of ATP and RNA, but in vain. The whole broadcast was liberally sprinkled with impossible over-technicalities, without the slightest attempt being made to explain them. There was talk about "resolving power", as if the general viewer had the remotest idea of what was implied. Worse still, on one huge model the lecturer, in passing, said: "Here is the Golgi apparatus", and left it at that! This is a violation of the most elementary canons of instruction. The fault surely lies with the producer, who ought to know his medium and his audience, rather than with the lecturer, who would I am sure invariably accept informed instruction on such matters.

The impression given at the beginning of the programme and by the *Radio Times*, that we were going to enjoy an *international* discussion was misleading. In the event it merely turned out that we had some pieces of quite indifferent film from the U.S.A. and from the U.S.S.R., with a snippet thrown in from Paris. One piece of the U.S. film was, in fact, cut off too soon. Out of all of this rather disappointing material the only single item which stood out was the vivid personality of Prof. Urey of California.

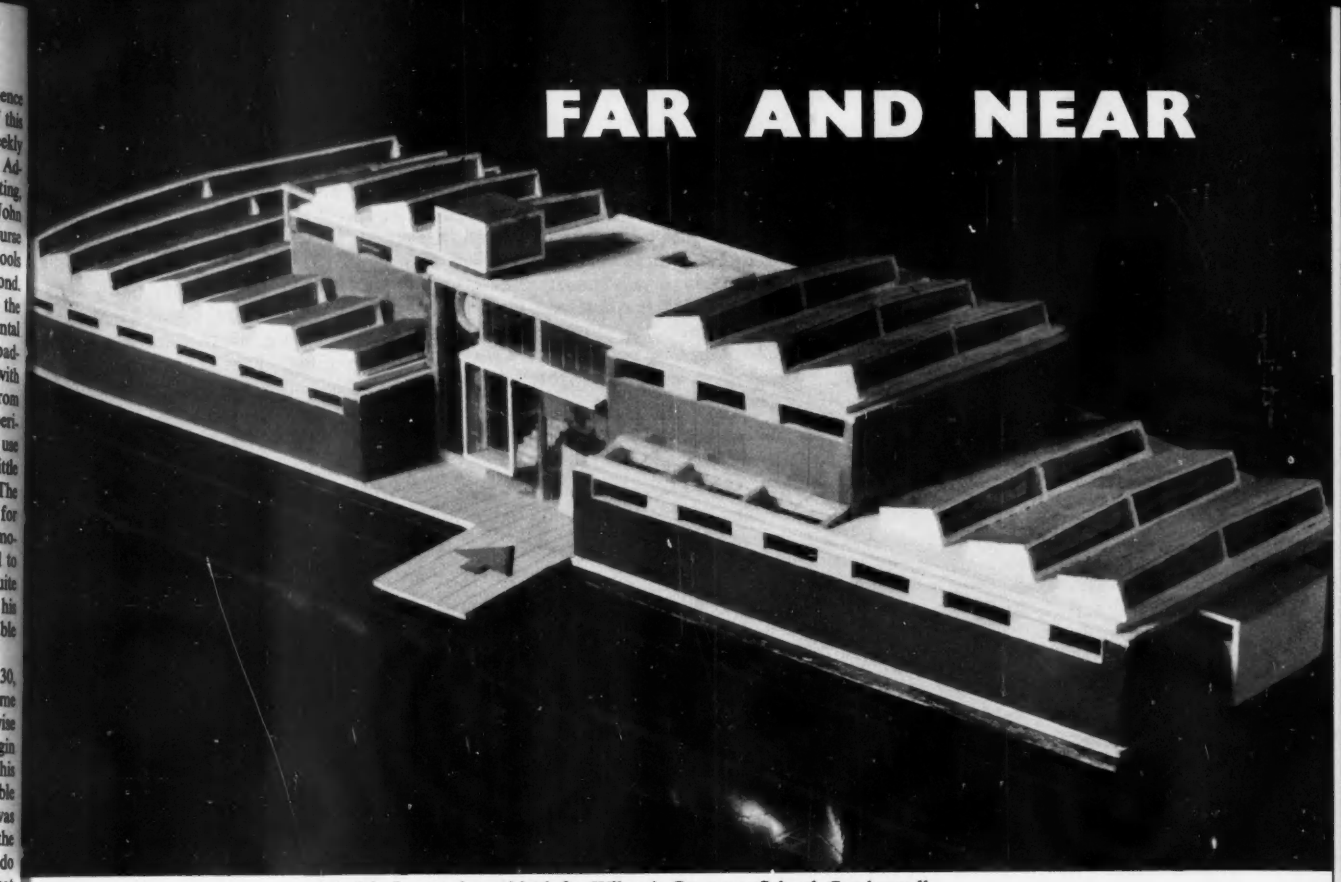
Having reviewed the main scientific excitements of the month, there remain for consideration the much quieter, yet none the less important, schools science broadcasts. ITV has for the whole of this school term been putting out a weekly series (duplicated) entitled "Endless Adventure", which, by the time of writing, had reached number 8. Produced by John Frankau, it is an illustrated lecture course given by that most admirable of schools television broadcasters, John Richmond. The object appears to be to show the historical evolution of experimental science. For instance, the number 7 broadcast (November 23) dealt essentially with Galileo and Newton, and apart from some neatly illustrated simple experiments was notable for the judicious use of excellent short film sequences and little playlets in the costume of the times. The impersonation in costume of Newton, for instance, makes quite an effective emotional appeal to the young. I was glad to see that John Richmond did appear quite frequently before the camera, for his personal touch makes a considerable difference.

The eighth broadcast, on November 30, was entitled "Power". In this, some defects tended to mar an otherwise reasonably good broadcast. To begin with, the producer slipped back into his old favourite device of having an invisible John Richmond. Again, all we heard was a phantom voice, with no sight of the teacher. Some may argue that children do not want to see the teacher. I argue that if this is the case, then why have television at all? Why not stick to sound broadcasting? The personality of the teacher is, to my mind, the first and prime visual in a television broadcast, and to reduce him to a phantom voice is to weaken the whole impact of the medium.

On this occasion the broadcast suffered from a further defect, admittedly unusual with John Frankau. The content was appreciably overloaded. First Kepler, then Torricelli, and finally a long jump to early coal mining. It was a little overwhelming and confused in content for the young, and this was a pity, for there was some excellent material in the broadcast. There were many colourful illustrations and it was clear that much care had gone into the production of some quite telling pieces of short historical film, especially that devoted to early coal mining. A little less content, some definitive recapitulation of main items, and at least an occasional glimpse of John Richmond would all have improved considerably a programme which, despite its obvious defects, was still reasonably good. This is, after all, schools broadcasting, and its function is to *teach* as well as to entertain. It is axiomatic that children can absorb only surprisingly little at any one session, especially if there is failure to hammer home by effective recapitulations.

S. TOLANSKY

FAR AND NEAR



Model of new science block for Wilson's Grammar School, Camberwell.

New Science Block for Wilson's Grammar School, Camberwell

A new-style modern science block, designed by Arthur Kenyon, Tauté, and Partners, is to be built for the ancient foundation of Wilson's Grammar School at Camberwell.

The building has been designed as a first object-lesson in science to stimulate the student's interest in his subject.

Piping and ducts for heating, electricity, gas, water, and drainage, are all exposed to view and painted in distinctive colours so that their course is easily discernible.

Scientific equipment has also been arranged to display its full mechanics to the student's eye.

Evenly distributed daylight is obtained throughout the building by roof lighting —an unusual feature in school design. Valuable wall-space is thereby freed for equipment and fittings.

A spacious central corridor serves all rooms, with a staircase to an upper floor containing biology laboratories which occupy only half the area of the ground floor, thus allowing roof lighting throughout. A pool for biology specimens and an aviary are enclosed in a small walled garden. Work will start early next year.

British Vacuum Committee

Following the Institute of Physics' London Conference on high vacua, held in April last, various suggestions were made for arranging regular British meetings on vacuum science and technology, and for British participation in international conferences in this field.

As a result of informal discussions between societies and institutes in this country, a "Joint British Committee for Vacuum Science and Technology" has now been formed. The committee consists of representatives from each of the following bodies: The Institute of Biology, The Institution of Chemical Engineers, The Royal Institute of Chemistry, The Institution of Electrical Engineers, The Iron and Steel Institute, The Institution of Mechanical Engineers, The Institute of Metals, The Institute of Petroleum, The Physical Society, The Institute of Physics.

Its objects are: to co-ordinate and help to initiate meetings in the whole field of vacuum science and technology arranged by constituent bodies; and to act in the collective interest of the constituent bodies by maintaining liaison with the International Organisation for Vacuum Science and Technology and with national vacuum societies, and otherwise.

The Institute of Physics has agreed to provide the secretariat for the joint committee; communications should be addressed to the Secretary of the joint British committee at its headquarters, 47 Belgrave Square, S.W.1.

Gold Medal Award for Doppler Scientist

The man responsible for the conduct of weapons trials at the Woomera Rocket Range received from the Duke of Edinburgh the 1959 Gold Medal of the British Institute of Navigation.

He is Mr John Ernest Clegg, English-born scientist, who has been working for the Australian Department of Supply since 1952. He is now Superintendent of Trials Division of the Weapons Research Establishment.

The Institute's award is in recognition of an achievement which the Institute says in its annual report is a "landmark in the progress of air navigation". This is the development of the famed Doppler navigation system. Mr Clegg's originality, drive, and foresight were major factors in putting the RAF ahead in the installation of Doppler equipment in operational aircraft, says the Institute.

Mr Clegg worked on the system at the Telecommunications Research Establishment, Malvern, England, for several years before going to Australia. There he continued the work and developed a

Doppler navigation aid which has been accepted by the RAAF.

He is in England at present preparing for forthcoming *Blue Streak* trials at Woomera.

More Science from the BBC

A Science Unit has been established by the BBC with the object of providing a more extensive coverage of science in sound programmes. The senior member of the Unit is Dr Archie Clow, who joined the BBC in 1945 and has produced many science series and individual talks, notably the two weekly series, "Science Survey" and "Who Knows?", in which leading experts deal with all kinds of scientific developments in a non-technical way. The Unit is also responsible for "Science Review" and Third Programme science talks and discussions.

Recently, Mr David Edge joined Dr Clow in the Talks Department. Both received their earlier education at Aberdeen, the former at Aberdeen Grammar School and the latter at Robert Gordon's College. Mr Edge did research work in radio-astronomy for three years after taking his degree in Physics at Cambridge in 1955.

A third member of the Corporation staff who is contributing to the expansion of science broadcasts is Mr C. L. Boltz, who is now attached to News Division as Science Correspondent. He formerly worked for seven years in a similar capacity in the BBC's European Service. In his new post he will deal with science matters both in sound news programmes and also in television. Since October 30 he has been broadcasting a short science news bulletin in the Home Service on Fridays, at 10.55 p.m.

Succeeding Mr Boltz in the European Service is Bryan Silcock, who was born in Liverpool in 1933 and has, since 1957, been an assistant editor of *Nature*. His father's practice as an architect has taken his family to Manchester, Germany, and elsewhere. He went to Dartington Hall School in Devon, and after National Service in the West Yorkshire Regiment and the Royal Artillery, to Jesus College, Cambridge, graduating with honours in Natural Science.

Improved Microfilm-Microcard Reader

The Dutch "Dagmar" microfilm-microfiche reader, which was noticed in these columns in January 1958, has now been made more versatile by the addition of an adapter which will enable it to take Microcards. This has been developed in the library of the Manchester College of Science and Technology, and it is now being manufactured for sale to others.

A library which already has a "Dagmar" can effect the small alteration necessary to take the adapter in a few minutes. A hole has to be cut in the front panel above the lens and a triangular casting bolted on. This takes the condenser system of the adapter and positions the illumination so that it shines down on to the Microcard which is in the glass microfiche holder. The image is then reflected from the surface of the card, through the lens on to the mirror and so down on to a sheet of white paper on the table top. A photocopy of the enlarged image can easily be made by putting a piece of document copying paper under a sheet of plate-glass in the position of the image. An exposure of 10 to 20 sec. is necessary. The adapter is being distributed by Trew Microfilming of 22 Park Lane, Croydon, at about £19.

Science Academy Plans Space Research

The Australian Academy of Science has drawn up a two-year programme of space research involving the use of rockets and balloons.

Prof. L. G. Huxley, convener of the Academy's recently appointed Committee on Space Research, said that standard rockets like the *Skylark*, which had already been fired at Woomera, could be used.

He said the Australian programme would include research into the circulation of the atmosphere, electrical properties of the upper atmosphere, meteor dust, cosmic rays, and the emission of light in the upper atmosphere.

The Australian Academy has deferred a decision on an invitation to put instruments into an American satellite.

Radio-Guide in Moscow's Museums

Visitors to museums and art galleries in Moscow may, in future, have no need of a guide to accompany them and explain individual exhibits or works of art. Equipped with tiny portable radio receivers, they will be able to tour the galleries, singly or in groups, listening-in to a commentary transmitted directly to them from a small radio station in the building. The radio station will have at its disposal a group of experts who will broadcast explanations in a number of languages.

The "radio-guide" will also be fitted with a small microphone, so that visitors can ask questions, the replies being transmitted to them immediately by one of the experts in the studio.

Air Survey of Antarctic

Australia will launch the largest aerial survey of the Antarctic yet undertaken early this year.

Two aircraft operating from a new ice airstrip near Mawson, the main Australian base, will fly missions round the clock through the long daylight hours, penetrating far into the untracked frozen wasteland.

Aircrew will use a Dakota and a single-engine de Havilland Beaver. The Dakota, the largest aircraft to operate with the Australians in the Antarctic, is in Sydney being fitted with special camera equipment.

Lightning Recorders

About fifty so-called lightning recorders have been erected at various places in Norway to give information about strokes of lightning. Provisional reports from recorders already erected indicate that strokes of lightning are much more frequent than expected. The purpose of these investigations is to clarify whether some areas are more prone to be struck by lightning than others, and when a survey of the density has been obtained, this will form the basis for deciding, for instance, where power-lines should be laid. The recorders were in operation during May to October, but investigations will be carried out over a period of five years.

Kodak Order a Computer

To keep pace with the requirements of an expanding business and to improve further the service to their customers, Kodak Limited have placed an order with EMI Electronics Limited for an EMIDEC 1100 all-transistor computer.

The computer will form the nucleus of an electronic data-processing centre to take care of the accounting, stock recording, and production-planning activities of the company.

From each of Kodak's nine United Kingdom branches, information regarding deliveries of goods to customers will be sent to the data-processing centre in the form of punched paper tape, where it will be processed at electronic speeds.

World's Northernmost Seismograph

The world's northernmost permanent seismograph will soon be installed at the meteorological station at Isfjorden in the Spitsbergen archipelago. The seismograph, a vertical one, will, together with two horizontal ones to be installed at a later date, constitute a seismological station of Grade I, which will be of the utmost importance. It will also be able to register nuclear explosions.

Halden Reactor

The new heavy-water boiling reactor at Halden, in south-east Norway, started up in June. It is being run as an experimental reactor for three years, according to an agreement with the OEEC. Nuclear scientists from all over Western Europe will follow the performance of the reactor, which is the only one of its kind in the world.

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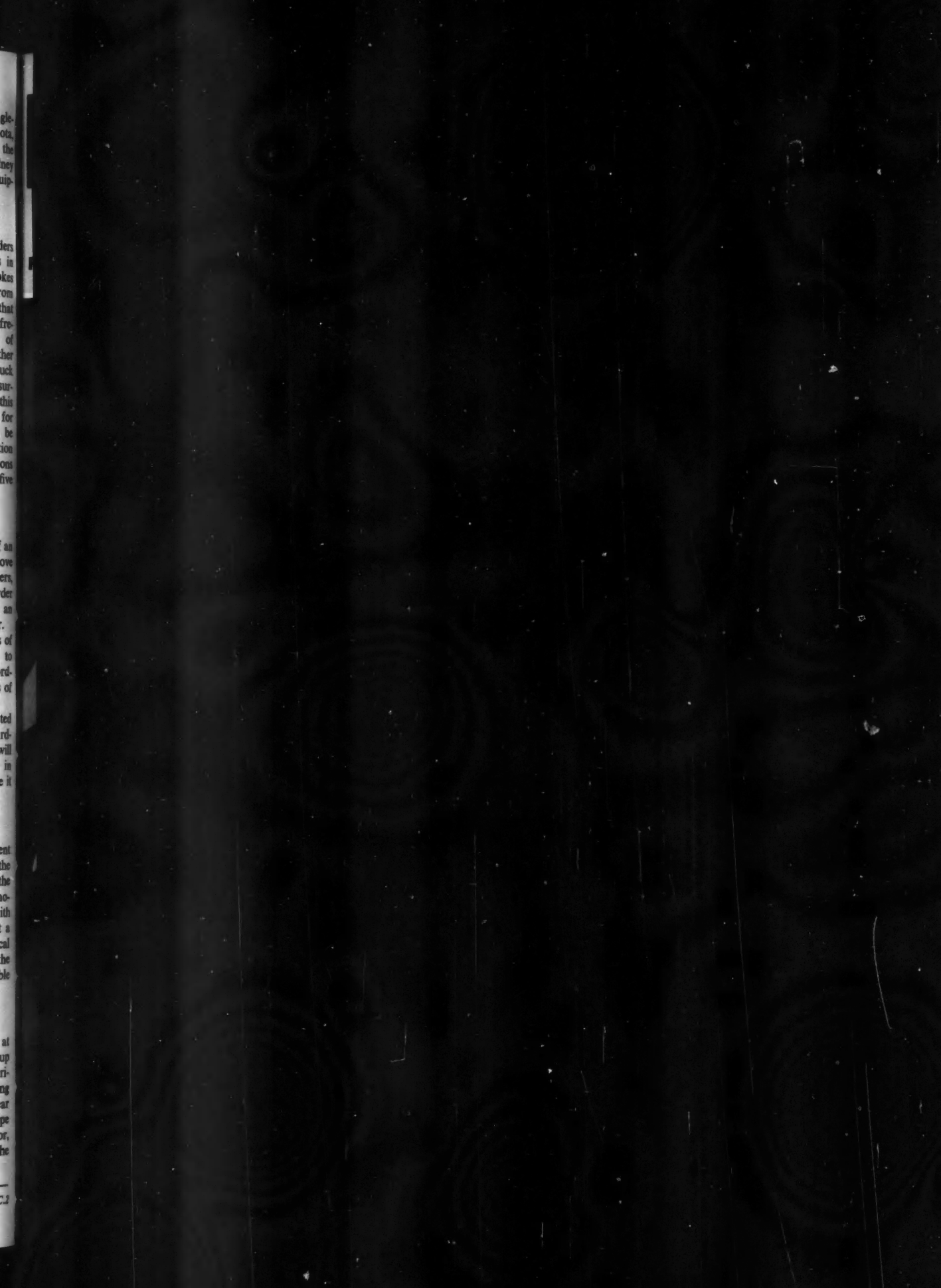
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